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MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XXVIII.

SESSION 1868-69.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1868–69.

November 17, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

Mr. Gregory, President, said that, before proceeding to the ordinary business of the evening, he desired, on behalf of the Council, to congratulate the members on meeting that evening for the first time in their new house. In a few weeks' time, at the Annual General Meeting, the Council would have to give an account of their stewardship, and to receive the Institution's verdict as to their proceedings generally, including their acts in reference to that building. Meanwhile he need hardly point out to them, as practical men, the reasons why they assembled there, without having attempted to complete the decoration of walls not yet perfectly dry, and without having hung the pictures which would improve the appearance of that room, or placed the bookshelves and the books in the library. With all the pains taken, there might be some shortcomings for which they would have to ask indulgence, and to the remedying of which they should devote their best attention. But in any case, they had thus far arrived at a result which was very satisfactory to the Council, and which he hoped might be pleasing to all. Within a period scarcely exceeding five months, the old premises had been removed, the ground lowered to a depth of nearly 20 feet below the level of the street, and that building, such as it was—handsome and convenient as he believed it to be—had been erected in its place.

They were indebted to combined labours for this result. In Messrs. Holland and Hannen they had contractors of well-merited repute for energy and resources, which had been applied with hearty good-will; and in recognition of the skilful labours of their architect, Mr. Wyatt, the Council had that evening passed a unanimous and cordial vote of thanks to him for his very valuable

services. They all knew their Secretaries so well, that he need hardly tell them that their unremitting and thoughtful attention had largely contributed to the successful result of that important work.

Some might be of opinion that the erection of that house was no unworthy commemoration of their 50th anniversary; but whatever might be thought upon that point, he was sure all would unite in the hearty and sincere desire that the opening of those new rooms might inaugurate an era of increased prosperity to the Institution and to the profession—an era which should be marked by greater usefulness to the world in general, and by a perfect feeling of unanimity, concord, and good-will among the members of the Institution.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye Laws, as Students of the Institution:—Charles Toler Burke, George Ernest Faithfull, Henry James Samson, and Herbert de Symons Skipper.

No. 1,203.—"On Lighthouse Apparatus and Lanterns."[1] By David Marr Henderson, Assoc. Inst. C.E.

When Mr. James T. Chance's Paper, "On Optical Apparatus used in Lighthouses," was read during the session 1866-67,[2] the Author of the present Paper was requested to describe the mechanical construction necessary for lighthouse apparatus and lanterns. In compliance with this request, the following notes are submitted, with the hope that they may prove of interest, as they are connected with a subject of the highest importance, viz., the protection of life and property along the sea-coast; the endeavours of the engineer being to render coasts navigable, and the entrance to harbours practicable, at night as well as during the day.

The manufacture of catadioptric apparatus for lighthouses was for many years almost exclusively carried on in Paris, where it was first introduced by Augustin Fresnel, a talented Engineer of the Ponts et Chaussées. At the present time there are three firms in Paris continuing this manufacture, consisting of the two old-established firms of MM. Henry Lepaute, and Sautter et Cie., and the recently established one of Barbier et Fenestres.

The apparatus of several lighthouses was made in England after Fresnel's brilliant success; but the manufacture cannot be said to have been established in this country till the year 1850, when the

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi. p. 477, *et seq.*

Messrs. Chance, of Birmingham, having engaged the services of a French foreman already skilled in the manufacture, started, with their usual energy, a department for the manufacture of lighthouse apparatus.

For several years the manufacture was confined to the production of the optical portion only, the lamps, rotatory machines, and lanterns being supplied by other makers, a considerable portion being imported from France. In 1858, the Messrs. Chance decided upon extending their lighthouse department, and upon commencing the construction of lanterns and the other mechanical portions. M. Masselin, one of the old pupils from the École Centrale, Paris, and who had been for several years employed by the Messrs. Chance, was the Engineer entrusted with the carrying out of this enlarged programme, and the Author was fortunate enough to be engaged as his assistant from 1858 till the spring of 1863. A short but interesting Paper, "On the construction of Lighting Apparatus for Lighthouses," was read before the Institution of Mechanical Engineers, at Birmingham, by M. Masselin, in 1862.[1]

The Author's first knowledge of lighthouse work was derived from M. Masselin and from the treatises of Messrs. Alan and Thomas Stevenson; and much information on the formulæ used in calculating the sections of glass was received from Mr. James Chance. The Mémoire[2] of M. Léonce Reynaud, Inspecteur Général des Ponts et Chaussées, and Director of the French Lighthouse Service, is one that should be studied by all concerned in lighthouse engineering, as it gives almost everything necessary for the engineer; the only point to be regretted being, that it does not enter into the details of manufacture, which are of considerable interest.

Glass used in Lighthouse Apparatus.

Nearly the whole of the glass used in lighthouse apparatus is made at Saint-Gobain, or Birmingham, and is known by the name of crown glass.

Different mixtures have been employed; thus at Choisy-le-Roi, in 1835, the mixture put into the pots was—

Sand	335
Carbonate of soda	165
„ lime	40
Arsenic	2
Cullet, or scrap glass . .	40
	582

[1] *Vide* Institution of Mechanical Engineers, Proceedings, 1862, p. 48, *et seq.*

[2] *Vide* "Mémoire sur l'Eclairage et le Balisage des Côtes de France." Par M. Léonce Reynaud. 4to., with folio atlas of plates. Paris, 1864.

An analysis of Saint-Gobain glass, some years ago, gave—

Silica	75·00
Lime	6·40
Soda	17·60
Alumina	0·37
Oxide of iron	0·15
	99·52

whilst M. Reynaud now gives the following analysis :—[1]

Silica	72·1
Soda	12·2
Lime	15·7
Alumina and Oxide of iron	Traces.
	100·0

A vegetable alkali, even after purification, contains some sulphates and oxides which colour the glass made from it, and in order to neutralize their injurious effect, manganese and cobalt were added. M. Allut gave as the most perfect composition, 300 lbs. of sand, 200 lbs. of vegetable alkali, 30 lbs. of lime, 32 ozs. of manganese, 3 ozs. of cobalt, and 300 lbs. of cullet. This mixture was costly, and gave various results, the difference of which was probably due to the varying nature of the alkali. Vegetable ashes ordinarily contain from 5 to 10 per cent. of alkali, so it will easily be perceived that large collections of ashes had to be made from different places, and that it was practically impossible to secure a uniform quality. Recourse was naturally had to a mineral source for the alkali required, and this enabled large quantities to be furnished of uniform quality at a much cheaper rate. Soda is used in three forms, as sulphate, nitrate, and carbonate, the object being to supply a sufficient quantity of alkali to the silica.

The glass for optical apparatus has in many cases been made at Birmingham from the following mixtures—

	Cwts. qrs. lbs.	Cwts. qrs. lbs.	Cwts. qrs. lbs.	Cwts. qrs. lbs.
French sand	5 0 0	5 0 0	5 0 0	5 0 0
Carbonate of soda	1 3 7	1 3 14	1 3 21	1 2 0
Lime	0 2 7	0 2 10	0 2 0	0 2 7
Nitrate of soda	0 1 0	0 1 0	0 1 0	0 1 0
Arsenic	0 0 3	0 0 2	0 0 2	0 0 3
Carbonate of potash	..	..	..	0 1 12
Red lead	..	..	..	0 1 0

The latter mixture, containing red lead, was called 'extra white,' but its manufacture has been discontinued for some years. All the English glass is supposed to be of the refractive index of 1·51.

[1] *Vide* "Mémoire sur l'Eclairage et le Balisage des Côtes de France," p. 85.

The Saint-Gobain glass formerly had an index of refraction as low as 1·50, but now it is 1·54, and frequent experiments are made to see that it is kept up to this standard. Flint glass was used in the construction of the small catadioptric, or totally reflecting spherical mirror, made for the Commissioners of Northern Lights in 1862. The mixture employed was—

	lbs.	ozs.
Sand	400	0
Red lead	320	0
Potash	112	0
Bristol lime	2	0
Nitrate of soda	7	0
Manganese	0	1
Cullet	280	0
	1,121	1

which gave a refractive index of 1·579. A previous experiment made with a mixture containing 20 lbs. less red lead gave 1·568 as the refractive index. Flint glass is not used for lighthouse purposes, as it is too costly, and much more liable to striæ than crown glass, which can be produced at a moderate cost, almost free from colour, hard, capable of receiving a fine polish, absorbing only a small portion of the rays of light during their transmission, and perfectly unaffected by the atmosphere. Whichever index of refraction, 1·51 or 1·54, be adopted for the calculation of the sections of glass, it is necessary that the glass be made to that index, otherwise loss of light will result from the incorrect shape of the lens rings and prisms.[1]

Furnace, Pots, and other appliances necessary for the Production of Cast-glass.

The glass furnace is generally a rectangular chamber in plan. Fig. 1, Plate 1, gives a side elevation and a transverse section, showing the two pots *a*, *a*, with the fire-grate, *b*, placed between them; the flame fills the whole of the interior of the furnace, and, after circulating round the pots, finds its exit by apertures in the sides. The furnace is placed under a high cone, so that the products of combustion are carried off, and at the same time a powerful draught is created. It is constructed of the most refractory materials, to withstand the intense heat; fire-bricks

[1] Babinet's goniometer is that generally used to measure the index of refraction of a piece of glass which is formed into a prism. If A be the angle of a prism, and D the angle of minimum deviation of a particular part of the spectrum (the extreme red ray is generally taken), and μ the index of refraction—

$$\text{Then } \mu = \frac{\sin. \frac{A + D}{2}}{\sin. \frac{A}{2}}$$

being used for the arching in the crown, but special blocks are employed for the 'sieges' and sides. Great care is necesary in the preparation of the pots, which are made of about one-half new fire-clay, and one-half old potsherds finely ground; the whole being worked into a plastic, homogeneous, and uniformly moist condition. A flat table is placed on the floor of the pot-room, and covered with lead, upon which the pot-maker builds up his pot, each piece of clay being finally kneaded and carefully applied by hand; a few inches only in height are added at a time, and then allowed partially to dry before another layer is superposed. One pot-maker has thus a great many pots on hand at one time; and when the pot-room is filled, the temperature is slowly raised, and maintained at about 100°, till the pots are thoroughly dry. Before being used in the glass furnace, they are placed in a pot arch and made white hot. The length of time a pot will last depends upon (1) the quality of its manufacture; (2) its being slowly and thoroughly dried—a process occupying several months; and (3), the care bestowed upon it in the furnace, and whilst withdrawn for casting. The average number of castings from each pot is about twenty; and the time that the pot is out of the furnace at each casting is about three minutes. Six, and sometimes eight, pots are placed in one furnace, which has its sides arranged for the easy withdrawal of the pots, the jointings of the large moveable side bricks being only stopped with fire-clay. The fuel is added through openings at each end, closed by a stopper, so that all the air to support combustion enters under the grate, and thus the pots are prevented from being damaged by a current of cold air striking against them. The pots are covered to prevent the colour of the glass being injured by any dust or impurities from the coal. It ought to be mentioned that the Siemens' Regenerative Furnaces are peculiarly applicable for the manufacture of lighthouse glass, from the intense heat they produce, the facility they give in regulating the temperature to suit the different parts of the process, the freedom from dust, and the economy of fuel. They are now used for the manufacture of lighthouse glass with perfect success.

When the metal is ready for casting, the side parts of the furnace are removed, and a pot-setting machine, shown in Fig. 2, Plate 1, is advanced, its jaws being made to enter the groove in the side of the pot, as shown at *c*, on Fig. 1. The pot is then lifted from its seat, withdrawn, and carried to the foot of the crane that hoists the pot to the level required in casting. Fig. 3, Plate 1, gives a side elevation of a useful form of crane. It is light and portable, being chiefly of wrought iron; is not liable to be destroyed by the great heat, and, being curved, gives a large available space for the manœuvring of the pot. At Saint-Gobain, a crane with a straight jib is used, and the post moves in a groove formed in a beam overhead, to do away

with the necessity for counterbalance weights. The lifting chain has attached to its end a clip, constructed to embrace the pot, and to enable the workmen to tip it over, by means of long handles, when the casting is to be done. A mouth-piece of copper is fitted to the pot before casting, to facilitate the pouring. Fig. 4, Plate 1, represents the casting-table, which is circular, and mounted on a frame, so that by means of a handle it can be turned round, and each part of its outer circumference brought consecutively under the pot of melted metal. The moulds into which the glass is to be cast are arranged round the outside of this table, and caused slowly to revolve under the continuous stream of liquid glass flowing from the melting-pot, so that each mould is filled in succession, thereby enabling the immediate return of the empty pot to the furnace. *d* is the top of the casting table, and *e e* are the moulds, arranged ready to be filled. The glass moulds are of cast iron, of a uniform thickness of $\frac{5}{8}$ inch, and are supported on feet cast on, the size being such as to allow $\frac{1}{8}$ inch thickness of glass all round for the grinding process. The small lens-rings and prisms are cast in one piece, but the larger ones are cast in segments. After the metal is run into the moulds, it is rubbed down with iron shovels, and all superfluous glass is removed from the edges, care being taken to reject any pieces in which defects appear; and it not unfrequently happens that defects in the melted glass are taken out by hooked points as the metal is run into the moulds, thus saving many pieces from being wasters. The cast glass—sometimes in the moulds, and sometimes after being turned out on to wooden handbarrows—is then removed to the annealing kiln, which has been raised to nearly the same temperature as the cast glass, and where it is gradually cooled down or annealed—a process requiring time as well as attention, otherwise the glass will be brittle, and not stand the grinding and polishing.

Before the casting process was adopted, the glass used to be melted in much larger pots, which were not taken out of the furnace, and the metal when ready was removed by a process called gathering, which consisted in dipping a wrought-iron pipe into the melted metal. A small quantity of glass at first adhered to the pipe; after cooling and dipping in a second time, a still further quantity adhered; and this process was repeated. Soon the limit of size was obtained; and for many of the usual sizes of prisms two different gatherings had to be employed. This method favoured the production of striæ, and caused many wasters, from the difficulty in uniting without flaw two pieces of plastic glass.

Glass Grinding and Polishing.

Sand, emery, rouge, and water, are the four necessaries. The sand requires to be clean and sharp, and to be applied with abund-

ance of water, till it loses its cutting qualities. The emery is generally obtained from Naxos, and arrives at the manufactory in irregular blocks, which are broken up with hammers, and then ground to a fine powder in a mill specially constructed with heavy rollers. The emery powder is then agitated in water, and the mixture passed through a series of separating cylinders of carefully arranged capacities, so that the emery is divided into as many qualities as there are cylinders, the coarsest being deposited in the first cylinder, the finest being in that furthest from the supply, where the emery remains longest in suspension. The rouge, which is an oxide of iron, is prepared from the sulphate, and has its coarse particles separated from the fine by means somewhat similar to those employed in the case of the emery. In both cases the coarse is rejected, and returned to be reground.

The glass of optical apparatus is ground on horizontal circular tables, securely fastened to the tops of wrought-iron vertical spindles, which receive their motion from the main shafting in various ways, but generally through the intervention of a short horizontal shaft driven from above by a belt, and carrying a bevil wheel, gearing into another on the vertical spindle, the whole being securely enclosed at the lower part of the machine. These tables have their surfaces divided out, like the face plate of a lathe, to receive the various sizes of carriers or supports of cast iron, which are bolted to them, and arranged to receive the lenses or prisms to be ground. The glass has to be accurately set for the production of the required section, only about $\frac{1}{8}$ inch being allowed on each side, and it must also be firmly bedded, to enable it to stand the heavy pressure applied in the grinding, but more particularly in the polishing, which generates a considerable amount of heat. After the carriers have been firmly bolted in their places, plaster of Paris is laid on them in bands, which are reduced to the exact size by turning the table round under a gauge secured to the framing of the machine. The glass is then laid on these strips, and secured in its place by means of pitch, care being taken in the larger sizes, which are ground in segments, to place a thickness of pitch between each joint, so that glass does not touch glass. The number of segments depends upon the number of panels into which it is intended to divide the apparatus; but in the smaller sizes it is better to grind whole rings, as, when desired, they are easily cut into pieces, by means of a diamond and a hot iron placed over the cut, which soon causes a perfect fracture across the prism.

Fig. 5, Plate 1, shows the method of grinding a belt or central lens of a fixed light; *f* is the section of glass, *g* the carriers bolted to the table *h*. To the left hand is represented the method of grinding the outer surface by means of the block *i*, and radial arm *k*, working round the centre of curvature *l*. This centre of

curvature is a fixed point in a bracket bolted to the main framing of the machine. The rod *m*, worked by an eccentric on an overhead motion, communicates motion to the grinding block *i* in an up and down direction, whilst the table revolves, carrying with it the belt. To the right hand is shown the method of grinding the inner face, where the grinding block *n* is worked up and down as before, and retained perfectly vertical by the guide block *o*, supported by a bracket bolted to the main framing. Fig. 6, Plate 1, shows the method of grinding the curved or reflecting face of a prism. The guide block *p* is curved so as to give the grinding block, which is also curved, the correct motion. An overhead eccentric works the rod *q* attached to the arm *r*, which by means of the link *s*, communicates motion to the grinding block. The rubbing face *t* is a loose piece of cast iron easily replaced when worn out, and it is held up to its work by the screw *u*. Guide rods *v* steady the block. Three and sometimes four blocks are at work on a prism at the same time, but all have a reciprocating motion, whilst the prism revolves, so as to prevent the cutting of grooves in the surface of the glass, and insure the uniform reduction of both glass and blocks. Curved guide blocks are necessary, as many of the radii of curvature are so long that it is impossible to use radial arms; but whenever practicable, it is preferable to employ a radial arm working round the actual centre of curvature. The eccentrics driving the blocks are made with a slot extending from their centre to near the circumference so that the extent of stroke may be regulated. The systematic arrangement of the machinery is a point of considerable importance, so as to enable all the usual sizes to be ground with the smallest possible stock of blocks, radial arms, &c.

Fig. 6*a*, Plate 1, shows the method of grinding a bull's-eye or central piece of an annular lens. The table revolves, whilst the grinding-block is turned in the opposite direction by the point *w* fitted in a vertical spindle driven by a belt. The first part of the grinding, or the roughing out, is done with sand; then follows the grinding with the various qualities of emery. When the grinding is finished, the glass must be free from scratches, and is carefully washed to remove all particles of emery. Then follows the polishing, which is done with rouge applied by blocks, having their working faces covered with felt.

Various Sizes of Catadioptric Lights.

There are six orders of catadioptric apparatus in general use, the first three being designated Sea Lights, and the second three Harbour Lights, but modifications in size have been made for particular cases:

1st. The largest size of apparatus is that known as the First

Order, having an internal diameter of 1·84 metre = 72·442 inches, and a height of glass of 2·704 metres = 106·447 inches. In the old section there were thirteen upper and six lower prisms, as shown in Fig. 8, Plate 2; but the section now generally adopted has eighteen upper and eight lower prisms, as shown in Fig. 17, Plate 2, so that the paths of the rays through the prisms are shortened; there is thus less loss by absorption, and greater accuracy is attainable.

2nd. The Second Order has an internal diameter of 1·4 metre = 55·119 inches, and a height of glass of 2·121 metres = 83·525 inches. In the old section, there were twelve upper and five lower prisms, as shown in Fig. 9, Plate 2; but the section now generally adopted has sixteen upper and six lower prisms, as shown in Fig. 18, Plate 2.

3rd. The Third Order has an internal diameter of 1 metre = 39·371 inches, and a height of glass of 1·56 metre = 61·435 inches, as shown in Fig. 10, Plate 2.

4th. The Fourth Order, being the largest of the Harbour Lights, has an internal diameter of 0·5 metre = 19·685 inches, and a height of glass of 0·739 metre = 29·112 inches, as shown in Fig. 11, Plate 2.

5th. The Fifth Order has an internal diameter of 0·375 metre = 14·764 inches, all the dimensions being $\frac{3}{4}$ths of those of the Fourth Order, as shown in Fig. 12, Plate 2.

6th. The Sixth Order has an internal diameter of 0·3 metre = 11·811 inches, all the dimensions being $\frac{3}{5}$ths of those of the Fourth Order, as shown in Fig. 13, Plate 2.

Another order has been introduced between the Third and Fourth, called the Small Third Order, having an internal diameter of 0·75 metre = 29·528 inches, and a height of glass of 1·144 metre = 45·056 inches, as shown in Fig. 14, Plate 2.

In addition to these there have been made, (1) the annular lens, shown in section, Fig. 15, Plate 2, for improving the old reflectors, and called the Seventh Order; and (2) an apparatus with an internal diameter of 0·15 metre = 5·906 inches, called the Eighth Order (Fig. 16), which has been used for small fishing stations, ships' lights, and for floating light vessels. These small orders have been designed, and almost exclusively employed, by the Messrs. Stevenson, of Edinburgh.

These various orders relate to the size of the apparatus, and consequently to the power, which is equivalent to the range, since suitable lamps are placed in the focus of each apparatus, as will be explained in the sequel. Care is therefore necessary in selecting the proper order of apparatus for each lighthouse, as by a too small order there will not be power enough to light the required distance,

and by a too large order there will be a useless expense, not only in the original cost of the apparatus, but also in the lantern, tower, and in the increased maintenance.

The various sections of apparatus already mentioned have been designed to suit oil flames, and the focal lengths chosen have such a relation to the size of the flame as to give a useful amount of divergence.

When petroleum takes the place of oil, if a disc be used in the centre of the circular wick, it becomes necessary to change the position of the foci, to suit the altered shape and condition of the flame. This has been done in France, and with very satisfactory results.

The Messrs. Hinks, of Birmingham, have patented an arrangement of petroleum burner, which does away with the central disc, and the Author designed a series of condensing lights, which were made by the Messrs. Chance, for the Crown Agents for the Colonies, in which the above lamps were, with a slight modification, successfully adapted to the ordinary sections of apparatus. This is a point of considerable importance, as it enables petroleum to be applied with beneficial results to the old apparatus constructed for oil lamps. Much remains to be done in the application of petroleum, as at present only burners with one circular wick have succeeded. Petroleum, from the greater whiteness, brilliancy, and cheapness of its flame, and its non-congelation through cold, is sure of a much more extended application than it has at present.

In the electric light, from its condensed size, the focus for all the parts of the apparatus is in a point, and from the shape of the carbon points, as great an angle of light is available below the focal plane as above it. Fig. 19, Plate 2, gives the section of a Third Order exhibited by the Trinity House at Paris, and Fig. 20, Plate 2, the section at present in use at Dungeness.

Distinction of Catadioptric Lights.

There are two grand classes of lights, as far as the effects they produce are concerned, viz.: fixed and revolving, but there are many combinations of the two plans. The former give a steady light of uniform intensity over the whole arc of the sea required to be illuminated; while the latter concentrate their light into parallel beams which, when the apparatus revolves, produce flashes preceded and followed by an eclipse or total darkness. In fixed lights, not illuminating the whole horizon, means should be adopted to utilize all the light not required in the non-illuminated arc. In dark arcs up to 180°, metallic or glass reflectors are used, but when these arcs are greater than 180°, the excess must be utilized by some other arrangement designed for the particular case, and it frequently happens that vertical condensing prisms, placed outside

a continuation of the fixed light, are the most advantageous.[1] When the whole horizon is not illuminated, vertical condensing prisms can sometimes be used for intensifying particular arcs requiring a more powerful illumination, or for showing a coloured light equal in intensity to the adjoining white light.

No general rule can be laid down for the apparatus, as each light has to be designed to suit its particular requirements. The Messrs. Stevenson have designed many condensing lights which display great ingenuity and are perfectly successful. The method of determining the shape of a prism by calculation, although simple, is a lengthy operation requiring great care from the number of figures used, and when a design containing a number of prisms has thus been worked out, it generally happens that some modifications are advisable—1, to equalize the sides of the prisms; 2, to suit the framing; 3, to cause the light to miss particular lantern standards. Even if the prisms are worked out from the calculated angles only, the operation is tedious and somewhat uncertain. To obviate this a Refraction Protractor was designed by Mr. Brebner, Assistant Engineer to the Messrs. Stevenson, which enables prisms to be drawn in with great speed and accuracy. After the arrangement has been decided upon, the prisms can be calculated to verify the setting out, and obtain the necessary dimensions for the grinding, without being liable to the inaccuracies of scaling.[2]

Some further modifications have been made in fixed lights to render them intermittent. Thus, at Minehead, in Ireland, the light is visible for 50 seconds at a time; the periods of light being separated by 10 seconds of darkness. This result is obtained by means of two screens, surrounding the flame, which suddenly cover and again uncover the flame, the necessary motion being obtained from clockwork placed in the pedestal supporting the optical apparatus. This light is highly characteristic, as there is a long period of light suddenly followed by total darkness, without the waxing and waning of the revolving apparatus; but there is this objection, that no use is made of the light generated during the periods of darkness, so that $\frac{1}{6}$ of the total quantity of oil burnt produces no useful effect. When the Author visited this lighthouse in 1863, to report upon the optical apparatus, he found the screens, from their inaccurate construction, causing considerable permanent occultation.

Oscillating vertical screens have been successfully applied in

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[1] The Author has seen two lights in which metallic reflectors for much more than half the horizon were employed, the result being that a considerable portion of light was effectually shut up inside the apparatus, and both oil and wicks were deteriorated by the heat.

[2] Mr. Brebner has furnished the Author with a description of this instrument, which is given in the Appendix, p. 31.

France, the first application being at the Pointe de Grave Lighthouse, in 1865. M. Henry Lepaute exhibited at Paris, in 1867, a Third Order, arranged to illuminate 72° of the horizon, with oscillating vertical screens darkening at regular intervals 18° and 25° respectively on each side of the apparatus. The mechanical arrangements were admirable, but no attempt was made to utilize the remaining 288° of light.

The revolving light, however, admits of a greater number of variations, as the flashes may vary from one every 2 minutes, to one every 4 seconds. Longer intervals have been adopted, but they, as well as the 2-minute flashes, are not liked by mariners, on account of the difficulty of identifying the light, and the length of time they are left in the dark. Combinations of fixed and revolving panels are adopted to produce further variety. Colour is applicable to both fixed and revolving lights, but only red, green, and blue are admissible, the former alone being suitable for sea lights, as the two latter have too limited a range. The amount of light absorbed by the colouring media varies from 55 to 90 per cent., depending upon the colour itself and the depth of tint employed. Red is a valuable colour, as it is difficult to mistake it for any other, and for equal intensities it has the longest range. Even in a fog when white lights are reddened, there will seldom be much to fear, as the mariner is well aware of the fact, and expects to find the white lights reddish, and the red ones rather deeper in tint. The red shades and chimneys used in France are of what is called pink ruby, which absorbs about 57 per cent. of light, whilst the ruby used in this country is called red ruby, giving a deeper tint than the French, but absorbing nearly 75 per cent. of light. Green and blue are only admissible for short ranges, as even in fine weather they cannot be seen far, and the least fog obscures them, more particularly the blue. In the winter of 1866, the Author had an opportunity of seeing the effects of red and green shades tried on a catadioptric Second Order light, at the Lowestoftness Low Lighthouse, which also showed a white light in certain bearings. At sea the superiority of the white was very marked, and the red gave a good result; but at about a mile, with a little fog, the green was hardly perceptible. The green shades have been replaced by red ones.

It will thus be perceived that, in fixed lights, there are two useful colours, white and red, by which distinction may be obtained, and these are sometimes employed in the same apparatus to mark particular arcs. Further distinction can be produced by rendering the light intermittent. In revolving lights the same colours are applicable, the flashes may be all white, all red, or combinations of both. Many ingenious arrangements have been carried out in France, for rendering the white and red flashes of equal intensity in the same apparatus, such as, proportioning the number of degrees condensed into each beam, and adopting different focal lengths.

Method of Mounting the Lenses and Prisms.

In sea lights, on account of their size and weight, it is necessary to divide the lenses into several portions. The section of the apparatus, consisting of lower prisms, lenses, and upper prisms, gives a convenient division into three tiers, each of which is subdivided into panels of a convenient size. In a First Order fixed light the circumference is divided into eight panels of 45° each, which are made of gun-metal racks, or side pieces, formed to receive the lenses and prisms, these side pieces being connected together with gun-metal segments of rings at the top and bottom.

Fig. 21, Plate 2, gives an elevation and section of one segment of a First Order fixed light. This is the arrangement in general use, all the joints of the panels being vertically over each other.

Fig. 22, Plate 2, is a general elevation of an arrangement with inclined lens-panels, and the upper prism panels are so placed that their joints do not come vertically over those of the lower prism panels.

Fig. 23, Plate 2, gives a half horizontal section through the focal plane of Fig. 22. In Figs. 21 and 22, *a* is a cast-iron column, bolted to the light-room floor, and having its top turned to receive the table *b*, which is free to revolve until the apparatus is placed in its correct position, when it is securely fixed by a set screw. An ornamental balcony *c* is employed to receive the lower prism panels *d*, carrying on their top the connecting ring *e*, on which are erected the standards *f*, one of which is placed behind each junction of the lens panels. When inclined panels are used for the lenses, the standards *f* are also inclined, and stays are introduced, inclined in the opposite direction, to obtain sufficient rigidity. A second ring *g* connects these standards at their upper extremities, and supports the upper prism panels *h*, which are connected together at their top by a ring *i*. This ring is sometimes stayed to the lantern, and forms a support for the ventilating tube. The lens panels *j* are held in their places by small dove-tail pieces entering into the top and bottom framing of the lens panels, and secured by means of screws to the rings *e* and *g*. The lens panels are made 1 millimetre shorter than the distance between the outside of the connecting rings *e* and *g*, in order that no weight may rest upon them from the upper cupola, an arrangement which is of great convenience during construction, as it enables the lenses to be taken down to dry after they are set, and to be out of danger whilst the cupola of upper prisms is being set. At the lighthouse also it affords greater safety to the lenses, because in a storm the whole apparatus is sometimes subject to considerable vibration, and in the case of a lens getting broken, the panel containing it can be taken down and sent for repair without interfering with the rest of the apparatus. In some cases a spare lens panel is supplied. In a few instances

the upper prism panels have been made to rest directly on the lens panels. The dotted lines in Fig. 21 show the position of a First Order lamp and burner.

Fig. 27, Plate 3, is an elevation, and Fig. 24, Plate 2, a horizontal section through the focal plane of a First Order apparatus, where the upper and lower prisms are fixed, and mounted as before explained, but the lenses *k* are annular, and mounted on a framework of wrought iron *l*; this revolves outside the fixed portion, and is bolted to the casting *m*, which receives a rotatory movement from the clockwork contained in the case *n*, by means of the pinion *o*, and wheel *p*, screwed on the outer edge of the casting *m*. The central column, which is fixed, carries the service table, optical apparatus and lamp, and has a projecting moulding upon it about half-way up, which is turned on its upper surface, and fitted with a steel ring *q*, forming the roller path for the friction rollers *r*. These rollers revolve round the central column, and are retained in their places by a connecting ring and guide rollers, working round the central column on a turned path. There are several modifications of this apparatus in use, as sometimes only a fixed light is shown in the lower prisms, and the upper prism panels are employed to intensify the flash from the lenses. The number of sides and the rate of revolution are also varied to produce distinction. The arrangement of the clockwork placed at the side of the central column, as shown in this figure, is essentially French; ample strength and solidity are obtained when only the lenses revolve, as the weight is inconsiderable. The cost of this arrangement is less than of that shown in Fig. 28, where a large square pedestal contains the clockwork.

Fig. 28, Plate 3, shows an elevation, and Fig. 25, Plate 2, a horizontal section through the focal plane of an eight-sided revolving light, collecting the whole light into eight beams of parallel rays. The usual speed of this apparatus is one revolution in eight minutes, so as to produce one flash per minute, but flashes at intervals of 8 and 10 seconds have been produced from a similar apparatus, by a slight change in the gearing of the clockwork. *s* is the pedestal with glazed doors, on the four sides, opening to give access to the clockwork. A small column is bolted to the top of this pedestal, which supports the fixed table *t*, carrying the lamps, and forms a guide for the revolving portions of the framework. *u u* are the friction rollers, working between the steel rings *y*, and secured to a connecting ring, carrying guide rollers, which work round the central column. As this is the part where the greatest wear occurs, care in detail is necessary. Steel rings and rollers edged with steel, all of the best quality, are fitted with the greatest accuracy, so that an equal amount of work may be done by each roller. Washers of various thicknesses are provided, to allow the course

of the rollers to be varied over the roller paths, so as to distribute the wear and prevent deep grooving. With every precaution there is considerable wear, and it is advisable to construct all the rings in halves, an arrangement which renders their renewal possible without taking down the whole apparatus. Brass rollers have been tried with a view to their receiving nearly all the wear, and thus save the steel rings, but they had this disadvantage, that they wore away so rapidly under the heavy pressure that in a few weeks they had large flat edges, requiring much power to grind them round, and producing an irregular motion which soon resulted in their total destruction. Conical rollers have been tried, but they are not much liked, as from the outward thrust there is a difficulty in keeping the rollers up to their work, and there is a large amount of friction against the ring holding them in. It should be remembered, however, that all these trials were made with roller paths of under 2 feet diameter, and with the same diameter of rollers as are now generally used, *i. e.*, about 5 inches. A more favourable result would be obtained from conical rollers with the large diameter of roller paths now used, reducing the outward thrust, and enabling twelve or more rollers to be used to carry the same total weight which formerly was carried by only six. Conical rollers are now being used by the Messrs. Chance. *v* is a carriage revolving round the central column, upon the friction rollers *u u*, and receiving its motion from the clockwork, by means of a pinion gearing into the internal gun-metal wheel *w* screwed to the revolving table *v'*. The two castings *v* and *v'* are bolted to each other. On the top of the casting *v'* are bolted eight wrought-iron standards, which carry the whole of the optical apparatus, fitted together in panels as before explained. At the top are guide rollers *x*, fastened to the upper connecting ring, and working round a turned roller-path, supported by a T iron framing attached to the lantern.

Fig. 29, Plate 3, shows an elevation, and Fig. 26, Plate 2, a horizontal section through the focal plane of a First Order apparatus, commonly called a "Fixed Light varied by short Eclipses," a title which certainly does not state the actual effect, viz., that of a fixed light followed by an eclipse, a flash, and an eclipse, the same phases being continually repeated. Figs. 26 and 29 show an apparatus consisting of four sides, of 45° each, constructed as for a regular eight-sided revolving light; and four complete segments, of 45° each, of a fixed light (as shown in Fig. 21, Plate 2), are fitted in between them, and the whole is mounted on a revolving carriage working on a fixed pedestal, as already explained. If the apparatus revolve once in 8 minutes, there will be 1 minute of fixed light, 26 seconds of eclipse or darkness, 8 seconds of flash, 26 seconds of eclipse, followed by a repetition of the same. In many of these revolving lights it is customary to leave out one of the

lower prism panels, so as to afford access to the lamp, but in some cases a hinged panel is used, and in others sufficient height is given to pass underneath, as shown in Fig. 42, Plate 4. In fixed lights illuminating the whole horizon, access can be had through a man-hole in the service table. Revolving lights are made of eight, twelve, sixteen, and twenty-four sides, to enable the intervals between and the intensities of the flashes to be regulated.

In Second Order fixed lights, the panels are made of 60° each, and revolving lights have eight, twelve, and twenty sides.

In Third Order fixed lights, the panels are made of 72° each, and revolving lights have eight, twelve, and sixteen sides.[1]

The method of framing Second and Third Order lights, both fixed and revolving, is similar to that adopted for First Order lights.

Harbour Lights, from their small size, are generally fitted together in one piece. Fig. 30, Plate 3, gives a sectional elevation, and sectional plan through the focal plane of a Fourth Order fixed light illuminating $\frac{3}{4}$ths of the horizon, the remaining $\frac{1}{4}$th having a silver-plated reflector. The lamp shown is a moderator, placed upon an adjustable stand for regulating the position of the burner. Fig. 31, Plate 3, shows an elevation and sectional plan through the focal plane of a six-sided revolving Fourth Order, mounted on a square pedestal containing the clockwork. The French arrangement of placing the clockwork at the side, and of having a small column to carry the apparatus, is in some cases convenient, in others necessary, on account of the small size of many harbour lanterns.

The construction of panels for the old lights was more complicated than the present method, as there was a regular framework or armature of wrought iron between which the panels were fitted. This framework caused great loss of light, from the joints sometimes having a thickness of $1\frac{3}{4}$ inch or 2 inches. The distances from the wrought-iron standards to the indented edges of the panels were filled in with gun-metal, and in the English apparatus no chipping pieces were used, so that the weight of gun-metal and the cost of fitting were much greater than in the modern method. The Author has always been an advocate for a reduction in the thickness of the sides of the panels, to economise light and gun-metal, and to enable all or nearly all the framework to be arranged by machinery in place of by hand. The indented or serrated racks were troublesome to fit, owing to the large extent of edges requiring to be accurately made to correspond. By the method now adopted, and shown in the First Order apparatus, much fitting has been saved, and, by casting the side racks recessed, with only a chipping fillet run round the edges, an economy of metal results,

[1] The number of sides may of course vary from those given, and it will be for the Engineer to determine the number suitable for the requirements of the lighthouse about to be erected.

and increased rigidity is obtained in the panels. Lining plates of gilding metal about $\frac{1}{16}$ inch thick are used to finish off the ends of each panel, and hold in the prisms; at the same time they cover all the recesses, giving the same appearance as if the racks were solid. The intermediate racks cannot be recessed, as there is no covering plate, but the thickness is only about $\frac{1}{4}$ inch, and they weigh less than the former thick indented ones. If desired there is no reason why these latter should not be cast indented as before. The racks are planed on both sides; the outer edges are filed, and the apertures for the prisms (when the castings are accurate) only require cleaning up. The upper and lower connecting rings are turned in one piece, or in segments fitted together. To make a panel, two racks or side frames are butted against the upper and lower segments of rings, and after a couple of wrought-iron screws have been put into each joint, the whole is soldered together, and, in the panels which have an intermediate rack, it is afterwards added in a similar manner. After the panels are made, they are erected upon a table having its upper surface turned and placed perfectly level, with a round centre rod accurately fitted in a socket, so that its centre corresponds with the vertical axis of the apparatus to be erected. By means of gauges, with semicircular ends fitting round this centre bar, and resting on adjustable collars, the panels are fitted in their places, and the holes marked out for the screws to hold the whole together. By the use of templates, and the accurate machine-work now applied to all the meeting surfaces, panels can be made interchangeable, which was impossible in the old arrangement of armatures produced by hand. The amount of clearance round each prism is $\frac{1}{8}$ inch, to allow for adjustment in setting the prisms, and for the putty used to secure the glass.

When the fitting is finished, the panels are taken to the erecting-shed, where they are erected on their pedestals, or on what is more convenient, a revolving table, specially constructed so that each panel, or part of a panel, can be brought in succession opposite the erecting-post. An arrangement of erecting table is shown in Fig. 7, Plate 1, where *a* is a ribbed cast-iron bedplate with a turned pathway *b* on its outer edge for the friction rollers *c*, and another turned pathway on its vertical central shaft to form a pathway for the guide rollers *d*. The top table *g* has a similar roller-path *e*, and guide rollers *f*, on its under side, and the top is turned and pierced with holes to enable the various sizes of apparatus to be secured to it. A wrought-iron plate *h* covers the central aperture, leading into a pit prepared for the reception of the driving weights of a rotatory machine, or mechanical lamp. As the operation of setting the glass produces much débris, from the plaster of Paris and putty used in fixing the prisms, the erecting-table should be designed to protect the friction and guide rollers

as much as possible from the dust. Apertures are provided in the bedplate to afford access to the guide rollers, and enable the whole of the interior to be cleaned without lifting the upper table. The inclined roller paths do not accumulate dirt and do not require oiling. The prisms are passed into their places, one end covering plate of the panel to be set being removed, and wooden wedges are used to support the glass and enable it to be accurately adjusted in its position by means of internal observation, as explained by Mr. Chance in his Paper. When the prisms are adjusted, plaster of Paris is applied at all the corners to retain them in their correct position, and when it is fairly set the wedges are removed and the remaining spaces filled in with best red lead putty. In the lens panels, as glass butts upon glass with only a thin film of cement intervening, there is no means of adjustment such as exists in the case of the prisms. The only method is to build up each lens panel, beginning at the bottom, and to make each ring correct before another ring is superposed. This latter fact has, up to the present time, prevented any attempt being made to readjust the lens panels in those lights whose upper and lower prisms have been readjusted, as this could only be done at the manufactory. The readjustment of defective lights is a point of importance, for by a small outlay, generally under £100 for a First Order apparatus, a great improvement has been effected and a good result obtained from the upper and lower prism panels, which frequently threw all the light falling on them where it was impossible to be seen. The effect of the lens panels in many lighthouses can be and has been improved by placing all the centres in one level plane with the inner surfaces vertical, and then putting the burner in its most advantageous position in the centre of the whole combination. The labours of the late Royal Commission on Lighthouses have led to the improvement of many defective lights in England and Ireland, and the supply of more perfect apparatus than had before been constructed. In Holland, also, the engineers entrusted with the lighthouse service have had two of their finest lights, at West Kapelle and West Schowen, readjusted under the Author's superintendence, with a beneficial result, which the pilots at once noticed and reported, without knowing anything of the alterations. But it must be borne in mind, that readjustment is only placing in the best possible position prisms incorrectly placed before, and that no actual improvement of the prisms themselves has taken place. It frequently occurs that a prism must be so fixed, as to throw the light too high at its centre and too low at each end, in order that the best result may be obtained from it at the sea horizon.

Arrangement of the Panels and Lantern Framing.

The arrangement of panels generally adopted is that of placing one panel over the other, so that the joints come vertically, over each

other ; and it has in its favour simplicity, a minimum loss of light, a minimum cost, and strong convenient-shaped panels. These advantages have been considered of such importance that in France the above method is still adhered to, and all the lanterns are constructed with vertical standards placed in front of the obscuration caused by the sides of the panels. Fig. 32, Plate 3, represents in elevation and plan this arrangement, which has the disadvantage of causing as many points, or rather small arcs, on the sea, as there are standards in the lantern, to be illuminated with a considerably weaker light. In front of each standard of a First Order lantern the light is weakened from 30 to 57 per cent. according to the thickness of standard employed, and there will be sixteen points on the horizon, when it is all illuminated, receiving this weakened light. In harbour lights the obscuration is frequently greater, on account of the small diameter of the flame and the thickness of the standards. The late Mr. Alan Stevenson, aware of this defect, was the first to introduce inclined lens panels, with a view to equalise the distribution of light on the sea, but he was well aware no doubt that there would thus be a diminution of light.

Several lighthouse authorities adopted a lantern with inclined standards, thinking to get over the difficulty connected with vertical standards, but no alteration was made in the construction of the optical apparatus. Fig. 33, Plate 3, represents, in elevation, the effect of an inclined standard projected upon the apparatus, and in plan the actual position is given. The horizontal divergence, resulting from the size of the burner, may be taken at 6°, and the standard is inclined over an angle of 7½° in plan, so that when an observer is placed in front of the standard, it nearly stops off the light from him throughout its entire height, commencing on one edge of the flame and finishing on the other, thus obstructing much light which had successfully passed through the apparatus. The defects of this system are apparent, as more light is stopped without there being any greater uniformity, and a more costly and unsightly lantern is obtained. The French Engineers have always seen and avoided this error.

The lantern of Mr. Douglass (M. Inst. C.E.), Engineer to the Trinity House, is designed to render impossible a correspondence, or optical coincidence, between the framing of the apparatus and that of the lantern. The effect is shown in Fig. 34, Plate 3, where the shaded portions represent the framing of the optical apparatus and the thick black lines the lantern framing. The framing of the apparatus stops 4·5 per cent. of the surface of the apparatus, and the framing of the lantern 6·8 per cent. of the surface of the lantern glazing, and as the two obstructions do not coincide the total loss becomes very serious. These lanterns are expensive, from the amount of workmanship of a costly class, and from the quantity of glass cut to waste.

To obviate the objections of the previous methods, the Author designed the following arrangements.

The first consideration is the optical apparatus, and it is apparent that a minimum amount of light is stopped by vertical panels, and that it is possible to divide the previous large obscurations into a greater number of smaller ones: thus equalizing the light without in the slightest degree increasing the total obscuration. By excentering, or placing the various tiers of panels so that their joints do not come vertically over each other, each previous obscuration is divided into three; the amount of excentering necessary depends upon the size of the flame, but it should be such as to enable one obscuration to be completely passed before entering upon another. In the First Order, for example, each panel subtends an angle of 45°; and, as there is an intermediate rack in the prism panels, there is an arc of $22\frac{1}{2}°$ between each obscuration. Each large obscuration can be divided into three small ones, which, if placed at intervals of $7\frac{1}{2}°$, will never allow more than one obscuration to be visible at a time, as the divergence of the flame is under 6°.[1] No practical difficulties or extra cost are involved in this arrangement.

The next consideration is the lantern, which, when arranged with excentered panels, is rendered less rigid, owing to the weight not being transmitted continuously downwards as is the case with vertical standards. This want of rigidity would be objectionable for a light illuminating the whole horizon, but in those illuminating from 180° to 270° (which are by far the most common), the objection might be easily overcome, as the dark arc could be filled in with solid iron plates, by which great rigidity would be obtained. When the frames are riveted together and the $\frac{1}{2}$-inch curved plate glass is in its place, additional strength will be obtained.

By the substitution of triangular frames in the central tier, it is still possible to retain the upper and lower panels excentered, and to render the framing perfectly rigid, in fact more so than with the vertical continuous bars of the old lanterns. This latter arrangement is peculiarly adapted for the employment of inclined lens panels. The result is shown in Fig. 35, Plate 3, where the shaded portions represent the framing of the optical apparatus and the thick black lines the framing of the lantern. Much light is saved by the coincidence of the two sets of framing.[2]

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[1] A Second Order light on this principle was constructed by the Messrs. Chance, in 1867, for the Krishna Shoal, India.

[2] When a lantern standard is placed in front of a junction of the panels in the apparatus it will stop a little light, as the diameter of the flame is greater than the thickness of the joints of the panels. This will not happen in the case of the electric light placed inside a large apparatus.

It may here be recorded that inclined prism-panels have been tried, but the loss of

Lanterns.

The sole object of a lantern is to enclose an optical apparatus, and prevent its being damaged by wind, water, or birds, so that the maintenance of a perfectly steady and high flame may be insured. The lantern should be designed to suit the apparatus, care being taken to get the necessary strength with the least possible obscuration of light, and its size should be such as to afford ample space for the lightkeeper to attend to his duties, at the same time avoiding too great size as a useless waste of money, which would be much better spent in establishing other lighthouses in localities destitute of them.

Sizes of Lanterns in most General Use.

Order.	Number of Sides.	Internal Diameter of Lightroom.	Height of Glazing.	Height of Focal Plane above Lightroom Floor.
		Ft. In.	Ft. In.	Ft. In.
1	16	12 0	10 0	11 6
2	12	10 0	8 0	10 10½
3	10	8 0	5 6	8 10½
4	8	6 0	3 6	4 7½
5	8	5 0	3 0	4 6
6	8	4 6	2 9	4 6

The lantern proper consists of the framing for the glass, the plate glass, a sole plate, an inner service gallery, with the necessary brackets to support it, steps to lead from the lightroom floor to the service gallery, and the cupola complete with the cowl. In the case of stone or brick towers the lightroom is frequently built of the same materials; but sometimes in stone, and always in iron towers it is constructed of wrought or cast iron. Fig. 36, Plate 4, represents a sectional elevation, and Fig. 37, Plate 4, a half sectional plan through the glazing, and a half sectional plan through the lightroom, of a First Order lantern with inclined standards. The lightroom is composed of sixteen cast-iron plates, eight large ones *a*, subtending an angle of 30° each in plan, and eight small ones *b*, of 15° each, fitted together to form a circular chamber of 12 feet 2 inches internal diameter, and an irregular polygon outside about 13 feet

light was found to be enormous, from the thickness and increased number of racks used in each panel to obtain sufficient strength, and from the fact that inclined racks darken portions of the prisms on each side of them. The injurious effects of inclined racks may be traced out by a diagram, but the result can be clearly proved by placing an inclined frame on any prism, lighting the lamp in its focus, and then receiving the shadow on a piece of white paper placed close against the rack.

across the corners. These lightrooms are frequently lined with mahogany, pine, or corrugated iron; a wood lining *q* is shown in Figs. 36 and 37, 1 inch thick, reducing the internal diameter to 12 feet. Eight ventilators, one in each small side, are generally employed, the construction being such as to prevent water entering, and with gun-metal hit and miss valves the supply of air can be regulated at will. The service gallery *c* is of open cast-iron plates carried on brackets *d*, bolted in between the flanges of the blocking, and steps *e*, provided with a handrail, lead from the lightroom floor to this gallery. A sole plate *f* is fitted on the top of the blocking, forming at the same time an outer gallery for the light keeper to stand upon whilst cleaning the outside of the glass. The standards *g* are sixteen in number, alternately inclined in opposite directions, so that the large side at the bottom becomes the small side at the top, and *vice versâ*; they are made of wrought iron, having feet passing down between the flanges of the blocking plates, to which they are secured by a couple of bolts for each foot. Two sets of horizontal gun-metal astragals *h* divide the lantern into tiers corresponding with the divisions of the optical apparatus, strengthen the framing, and assist in securing the plate glass. The standards are united at the top to a wrought-iron connecting ring, to which are attached the rafters *j*, about $1\frac{1}{8}$ inch square, covered in with an outer roofing of copper 3 lbs. to the square foot, and an inner roofing $1\frac{1}{2}$ lb. to the square foot. This inner roofing is sometimes of zinc or galvanized sheet iron. The cowl *k* is a revolving one of sheet copper, mounted on a spindle working in an oil cup at the bottom of the neck, and underneath is placed a hollow dish to prevent any drops of water that might accumulate inside the cowl from falling on the apparatus. A ventilating tube of copper *m* conducts all the products of combustion direct into the cowl, where they pass out by a number of 1-inch holes, which are always turned from the wind by the vane on the cowl spindle. The gutter *n* is of sheet copper, provided with a stiffening wire at its upper edge, and gun-metal joint-covers. A copper ladder rod is fixed to the underside of the gutter, and inside the lantern a similar rod or hooks are provided for the curtains. The glazing is of $\frac{3}{8}$-inch plate glass *p*, which is secured in its place by gun-metal strips and screws, and two tiers of handles facilitate its cleaning. Rain-water pipes, fitted in front of two of the standards, convey the water from the gutter to the foot of the lantern. Figs. 38 and 39, Plate 4, are details of a standard *g*, showing the connection with the astragals *h*, and how the glass *p* is secured. A facing strip of gun metal *i* is screwed to the standard, so that the glass rests in a gun-metal groove, and all the screws securing the strips which hold in the glass are screwed into gun metal, and are consequently easily removed in case of a pane being broken. Fig. 40, Plate 4, shows a detail of the lower

gun-metal sill *o*, resting on the sole plate *f*, which is bolted to the top of the blocking *a*. The mahogany lining *q* is secured to pine packing pieces *r*, wedged in between the flanges of the blocking. This lantern is objectionable, on account of the too small inclination of the standards and their non-coincidence with the joints of the optical apparatus. The large flat sides are ugly, and those of the blocking are easily broken, on account of the small depth of flange at the centre of the plate compared with that at the sides. The cost is increased by the more difficult workmanship, by more glass being cut to waste than with vertical standards, and from the fact that six different sizes of panes are used in place of three.

The French adhere to one form of lantern for all apparatus burning oil; a description of which may be of interest, to enable a comparison to be made with the lantern previously described. The example selected is the First Order lantern destined for the Roches Douvres, about half way between the islands of Guernsey and Bréhat, which was shown at the Paris Exhibition of 1867. Fig. 41, Plate 4, is an elevation, and Fig. 42, Plate 4, a sectional elevation of this lantern, with the apparatus also in elevation. The lantern standards are vertical, sixteen in number, and extend in one piece from the cornice to the bottom of the lightroom, which is formed of wrought-iron covering plates screwed to the standards and to the framing connecting them. The standards are faced with gun metal, and have gun-metal astragals, upper and lower sills to receive the plate glass, and ventilators fitted all the way round in the lower sill. The under portion of the cornice forms the gutter, which conducts the rain-water to a lion's head placed over each standard; whilst the upper portion is of open work, which improves its appearance, and hides the little ventilating boxes placed in the gutter. The cowl is fixed, and is provided with a moveable vane, to indicate the direction of the wind. The roof and all the parts exposed to the sea above the lightroom are of gun metal or copper. The roof is supported on a regular frame-work of iron, which also carries the steadying cylinder for the optical apparatus. The apparatus has twenty-four sides, and makes one entire revolution in 1 minute 36 seconds, so as to give a flash every 4 seconds. This great speed necessitated a special construction of clockwork, which was successfully accomplished by M. Henry Lepaute, who constructed the whole apparatus and lantern. The total weight of the revolving portion is 2 tons, and the driving weight 121 lbs., falling 66 feet in 6 hours. The regulator is the centrifugal one invented by Fresnel, and afterwards improved by M. Lepaute. The section of glass consists of nineteen upper prisms, a central lens, with eight lens rings both above and below, and eight lower prisms. A mechanical lamp burning colza oil is used, and the intensity of the flash is estimated at 2,475 becs carcels. The

whole of the armature was constructed with the least possible weight, to save the friction rollers, and sufficient height was given to enter the apparatus without omitting, or suspending on hinges, any of the lower panels.

Fig. 43, Plate 4, shows an elevation, and Fig. 44, Plate 4, a half sectional plan through the glass, and a half sectional plan through the blocking, of an arrangement of lantern designed to remedy the defects of previous lanterns.

The apparatus shown in Fig. 22, Plate 2, is arranged for the most uniform distribution of light practicable; and the lantern here described is capable of being put round that apparatus with only a small obstruction of light. The blocking is circular, of cast iron (but it may be of wrought iron), with wooden or corrugated galvanized iron lining; and sixteen ventilators are employed, one in each segment. An inner service gallery is carried on brackets, and a sole plate with outer cleaning path, rests on the blocking. It is preferred to make the framing of forged iron or steel, but it may be of cast iron. The quadrilateral frames in the lower tier are fitted together with vertical joints, and form a level surface on which rest the triangular frames of the middle tier, again forming a level surface for the upper tier of quadrilateral frames. A cast-iron gutter is shown, as it can be easily connected with the framing, rafters, and roofing plates, thus doing away with a considerable amount of workmanship.

Fig. 45, Plate 4, shows a detailed section of the framing, and how the plate glass is secured by gun-metal capping.

Fig. 46, Plate 4, shows in detail the connection between the framing, gutter, rafters, and roofing plates. There is a much larger air-space than usual, and the rafters have apertures in them to enable the air to circulate freely. Circular glazing is preferable to flat, on account of its greater strength, and as being better calculated to resist the action of the wind; besides the rays of light pass normally through it.

It would be well if one pattern of lantern could be designed to suit all apparatus; but it is impossible so long as different sizes of apparatus are employed with different numbers of panels to the circumference. At present one size of lantern is required for each size, and the problem is to arrange the best form of lantern for each class of light, and to select one that shall combine the greatest advantages for both fixed and revolving lights. The system last described affords the most perfect solution of this problem, as it gives a more equal distribution of light, with less loss than with any other method. A lantern without standards would be the most perfect, and would demand an apparatus without framing, but at present there are many practical difficulties in the way. The only attempt in this direction as yet executed, is by M. Sautter, of

Paris, for the electric light, where the size of the lantern is very small. The glazing is circular for 180°, with two flat sides extended to allow of an arc of 270° being illuminated, and is fitted together in pieces with butt joints. The cupola is supported from the side of the main lightroom by strong angle-iron rings. The Author prepared, about the year 1860, under M. Masselin, designs for an electric light lantern, with circular glazing for 270° without standards, the cupola being carried on the remaining 90°, which was formed of cast-iron plates. Two columns inside the lantern, but placed in the dark arc, extended from the lightroom floor to the roof, with the view of having abundance of strength and rigidity, so as not to endanger the glazing.

Catadioptric Mirrors.

Fig. 47, Plate 5, shows the first catadioptric mirror ever made, and which was used by the Messrs. Stevenson, in conjunction with a Sixth Order holophote, to condense the whole of the light from an argand burner into a beam of parallel rays. The internal radius was $12\frac{1}{16}$ inches, and the thickness of the joints was $\frac{3}{16}$ inch. Sufficient space was left at the top and bottom for the passage of the damper tube and burner of the lamp. In this case the mirror was constructed of flint glass. as previously stated, whilst crown glass was used in the construction of the holophote. The employment of flint glass was costly, as it had to be specially made, and great accuracy was necessary in jointing the various pieces together, making it improbable that such mirrors would be generally used.

Mr. Thomas Stevenson, M. Inst. C.E., originally designed these mirrors with the zones generated round the horizontal axis; but in this instrument Mr. James Chance, Assoc. Inst. C.E., introduced for the first time the plan of forming the zones round the vertical axis, being that of the flame. The advantages of this latter plan are important optically, in addition to facilitating the construction of the zones themselves, and enabling the mirror to be easily limited both vertically and horizontally.

Mr. Chance gives the following further account in his Paper already referred to.[1]

"During the progress of this instrument, the idea occurred to the Author of separating the zones, and also of dividing them into segments, like the ordinary reflecting zones of a dioptric light: by this means it became practicable to increase considerably the radius of the mirror, and thereby to render it applicable to the largest sea-light, without overstepping the limits of the angular breadths of the zones, and yet without being compelled to resort to glass of high refractive power.

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. xxvi. p. 499.

"The separation of the zones also rendered it feasible to avoid giving to the aggregate structure a spherical shape, which would have encroached most inconveniently upon the space required for the service of the lamp."

In determining the sizes of the mirrors, the chief consideration was to arrange as few sizes as possible, in order to diminish the cost by the small stock of glass, moulds, and gauges that would be required, and to enable them to be used in revolving as well as in fixed lights.

Fig. 48[a], Plate 5, shows a sectional elevation of a First Order mirror, placed inside a revolving light of the same order. The internal radius is ·75 metre, and the panels are ordinarily constructed of 45° in plan, so as to correspond with those of the apparatus. This size is equally applicable for both fixed and revolving lights.

Fig. 48[a], Plate 5, shows a sectional elevation of 90°, and a plan of one panel of 60° of a mirror of ·6 metre radius, which is applicable to Second Order fixed and revolving lights, and to Third Order fixed lights. The construction of these panels is similar to that already described for the prisms, and in general they are secured to cast-iron brackets, which are bolted to the service table of the apparatus, as shown in Fig. 48.

Lamps.

The lamps employed are of endless variety, but all have the same object, viz., to give a regular and abundant supply of oil to the burner.

In the Sea Lights the following sizes of burners are generally adopted—

Order of Apparatus.	Number of Wicks.	Diameter of Burner in inches.	Intensity in bees carcels.	Consumption per hour in lbs..
1	4	$3\frac{1}{2}$	23	1·677
2	3	$2\frac{15}{16}$	15	1·103
3	2	$1\frac{3}{4}$	5	·386

In the Fourth Order, a two-wicked burner, about $1\frac{3}{16}$ inch diameter, is used; but in the Fifth and Sixth Orders, single-wicked burners are generally employed, consuming from 0·17 lb. to 0·1 lb. per hour. The French have recently constructed a moderator lamp with two wicks, for the Fifth Order, which has considerably increased the intensity of light.

In most of the Scotch lighthouses, there is a larger consumption

of oil than is given in the above table, and consequently a greater intensity of light is obtained.

The three principal varieties of lamps now in use for sea lights are the mechanical, the high reservoir, and the pressure. The mechanical are the most general, being adopted in Scotland, France, and many foreign countries. The most perfect is that employed by the Messrs. Stevenson, and manufactured by the Messrs. Milne, of Edinburgh. A sketch of this lamp is given in Fig. 48, Plate 5. The French mechanical lamps also give excellent results. The oil, in both cases, is forced over the burner by pumps, which are worked by clockwork placed underneath and driven by a weight.

The high reservoir lamps have many varieties. One of the best is that designed by Captain Nisbet, of the Trinity House, and successfully applied to several English lighthouses. In this lamp the body is of copper, hammered to a vase shape, with plunger pumps inside to force the oil up to the high reservoir, from whence it descends to the burner by gravity, a fountain arrangement being provided, so that the pressure is always constant. The high reservoir is fixed to the armature in the non-illuminated arc, at such a height as to give a head of 6 inches or 12 inches of oil. If a greater head is employed, the pressure necessitates the regulating valve being nearly closed, and thereby rendered more liable to be choked up by flock from the wicks or other foreign matter. The feed pipe passes down to the service table and under its surface to the centre of the apparatus, where it mounts through the lamp body to the burner, and the supply pipe for the high reservoir passes side by side with it. Excellent provision is made for regulating the overflow by an indexed regulator worked by a thumb screw, and at the outer edge of the service table are placed cocks for drawing off all the oil. These lamps are costly, and are not applicable to revolving lights, or those illuminating all the horizon, on account of the obstruction of light caused by the high reservoir. This is a defect common to all lamps of this class.

M. Degrand, of Paris, designed a pressure lamp that forced the oil over the burner by means of a weight pressing directly on the surface of the oil. Several sizes were manufactured, giving a very fair result. The Messrs. Chance purchased some of these lamps, and in one that was used for experiments, it was found that the large space between the piston and the cylinder rendered the leather packing liable to turn over when the oil got heated and softened the leather. Added to this, no provision was made for varying the weights on the piston. To obviate these objections M. Masselin designed a lamp with external weights which has given excellent results, and has the advantage, not possessed by the high reservoir lamps, of being equally well adapted for fixed and revolving lights, whether the whole horizon is illuminated or

not. The lamp shown in Fig. 49, Plate 5, is essentially the Masselin lamp, but a few modifications of detail have recently been added. *a* is the service table, upon which is bolted the lamp-stand *b*, having upon its upper ring three screws *c*, for holding and regulating the position of the lamp. The apertures in the bottom flange of the lamp are large, so that room is provided for accurately adjusting the lamp in the centre of the apparatus. The body of the lamp *d* is made of a cylinder of sheet brass fitted into an upper and lower cast-brass ring, the whole being turned and bored previous to tinning the inside. The boring of the lamp barrel is essential, as by that means, and the turning of the piston *e*, so little room is left between them that it is impossible for the cupped leather packing *f* to turn over. The piston is of cast iron, and has six guides *g*, of leather, fitted edgeways between cheeks, so as to maintain the piston in the centre. A valve *h* is fitted in the centre, opening downwards, when the piston is raised, and facilitating the passage of the oil to the underside of the piston. It at the same time prevents the accumulation of air under the piston, as the valve only closes when the piston reaches the oil. A fine wire gauze is placed on this valve to exclude pieces of wick which might, through carelessness, enter the body of the lamp. The weights *i* are of cast iron, in discs, so that the weight can be varied at will; and connecting rods *k*, attached to the plate *l* at their bottom, and a ring *m* at their top, with a second set of connecting rods, apply the weight to the piston. All these connecting rods act as guide rods, by being passed through holes in the cylinder and cylinder cover. The weight is raised by a handle fitting loose on the horizontal spindle *n*, under the body of the lamp. This spindle carries two pinions gearing into the racks *o*, which are attached to the plate *l*, and work in guides cut in the flange of the cylinder bottom. A tap *p* is provided for emptying the oil, and *q* is the feed pipe, for conducting the oil to the burner, containing the valve *r*, and regulator *s*. The feed pipe passes under the cylinder cover and up the central column *t* to the burner *u*. The overflow oil passes over the burner, and is collected in the cup at its bottom, and conducted by a pipe *v* to the strainer *w*, composed of a fine plate of perforated tin, with fine wire gauze underneath, so that no flock or charred wick can enter the lamp cylinder. The valve *r* is cylindrical, with two apertures opposite each other, and when these are vertical the oil can pass to the burner, but, by turning the cylinder slightly round, the passage is closed, and the cylinder cover may be taken off—(only the oil contained in the valve being spilt)—when the cross filter can be cleaned or removed and replaced by another, the whole being easily readjusted in a couple of minutes. To prevent the tendency to draw down the oil from the burner during the winding up, a self-acting spherical valve *x*, of some light material, is placed over the

cylindrical one, so as to close whenever the piston begins to be raised, and remain so till the piston is released. The regulator *s* consists of a conical point which enters the feed pipe, (the distance it enters being regulated by a fine threaded screw,) and facilitates the regulation of the overflow. An index is placed so as to enable the light keeper, by inspection, to know the position of the regulator. Safety fountains are sometimes sent with these lamps, so that in case of an accident to the main lamp they can be filled with oil and set to work in a few minutes, by coupling their supply pipe to the union joint *y* of the lamp. The burners are screwed to the central column by the union joint *z*, and they are further steadied by a holder clipping the cup of the burner, which is of brass, accurately turned. By unscrewing two screws the burner can be detached and replaced by another always kept ready in the lightroom. The burners are interchangeable, and are all made to standard gauges, the concentric holders for the wicks being of sheet iron brazed, and then tinned. Each wick has two small feed tubes, one on each side, so as to insure an abundant supply of oil. The bottom of the burner is moveable, so that access can be had to the interior, for the purpose of cleaning the supply tubes. A chimney holder of brass fits over the burner, and its position is regulated by means of a couple of racks and pinions, to enable the light-keeper to place the shoulder of the chimney at the proper height, a point of great importance in the production of a good flame. The wicks are raised by small racks and pinions fitted to each wick-holder, and a number is conspicuously placed on the thumb-screw of each, referring to the number of the wick. To produce a good flame it is necessary to have an overflow of from three to four times the consumption, and the greatest care must be taken to light up slowly so as not to char the wicks. With care a good flame may be kept up for seventeen or eighteen hours without trimming. For harbour lights moderator or fountain lamps are generally used, and sometimes the reservoir is placed over the apparatus. A good overflow, however, should be maintained, as in the sea lights, otherwise the wicks char, and after a few hours cease to give a good flame. A damper tube is placed over each chimney, and the ventilating tube generally employed is the one introduced by the late Dr. Faraday with such excellent results. The chimneys are of flint glass about $\frac{1}{16}$ inch thick, carefully annealed, and it is important to give the correct form to the shoulder, so as to insure the production of a good flame, and to obstruct as little light as possible.

Clockwork.

Fig. 50, Plate 5, shows a First Order clockwork, consisting of two trains of wheels, one for driving the apparatus, and the other for driving a fly wheel with adjustable vanes for regulating the

speed. The driving weights are suspended by a rope wound round a barrel. Experience has proved that, (1) the wide barrel was objectionable, as the weight could not be passed directly down a small central column; (2) the rope wore out rapidly, and frequently let the weights fall; (3) the method of driving the fly wheel absorbed a large amount of power and caused difficulty in keeping the apparatus at its correct speed. To obviate the first two of these objections, the Author introduced a chain working in a toothed pulley, thereby enabling the weight to be passed directly down a central column. The chain was durable and not affected by moisture like the rope. The pulleys and chains employed were similar to those made for Weston's differential pulley blocks, and were supplied by the Messrs. Tangye Brothers, of Birmingham. This method has been used in many clockworks, but it requires great accuracy in the size of the links of the chains, otherwise slight jars are produced when the links leave the pulley. All the advantages of a chain might be got from a wire rope with Fowler's clip drum. By employing an endless chain or wire rope, a constant driving power is obtained, which is not the case with the ordinary barrel arrangement. To obviate the third objection recourse was had to the French plan, of driving the fly wheel by means of a bevil-wheel gearing into a small bevil lantern pinion on the fly-wheel shaft. There is, however, no necessity for a fly wheel, which is replaced in most of the French clockworks by a self-acting governor on the Fresnel or Foucault system. An indicating hand is arranged to make one revolution per hour when the clockwork is going at its proper speed, so as to admit of comparison with the lightkeeper's clock. A small supplementary weight was sometimes used to maintain the clockwork at its correct speed during the winding up, but the plan was not self-acting and required space for the falling of the weight. The Astronomer Royal proposed a plan, which the Author worked out in detail for the clockwork exhibited by the Messrs. Chance in 1862. This plan, as shown in side and end elevations, Fig. 50, Plate 5, was perfect and simple, as the reaction of the winding up was made to drive as long as the winding up lasted. Another arrangement is to have a small weight, on the end of a lever, which is raised during the winding up and by its falling maintains the clockwork at its correct speed, if the weight be properly proportioned. As soon as this weight reaches the bottom it is re-raised if the winding be still going on.

Odessa Harbour and Apparent Light.

For the entrance to this important harbour, Captain Illyne, of the Imperial Russian Navy, required a Fourth Order to be placed on the extremity of one breakwater, and on the other a light was to

be shown without having a lamp there, as he wished the whole of the manipulation at night to be done in one tower. (See the chart of the harbour, Plate 6). Captain Illyne had seen in Mr. Thomas Stevenson's treatise on 'Lighthouse Illumination' an account of the success of the Stornoway apparent light, and he was anxious to try a similar method at Odessa. The conditions were, however, different. At Stornoway, 62° were required to be illuminated, the maximum angle of deviation of a ray from its original direction was 121°, and the minimum 59°. At Odessa, an arc of 180° required illumination; the maximum angle of deviation was 180°, and the minimum 90°. A metallic reflector having a parabolic section in plan, and bounded by its latus rectum, would have solved the problem, but one of the conditions was that no metallic reflection was to be employed in the beacon. Fig. 51, Plate 6, is an elevation of the lighthouse; Fig. 52, Plate 6, is a vertical section. The tower is 23 feet high, made of three tiers of cast-iron plates, 6 feet internal diameter, and has its circumference divided into eight plates, as that was the most convenient number to suit the lantern, doors, and window for the holophote. The stairs are of cast iron, bolted to the side of the tower, and a wrought-iron handrail and balusters are fitted to the inside edge of the steps. A wrought-iron semifloor is fitted at the top of the first tier of plates, from which the service of the holophote is attended to. The lightroom floor is fitted to the centre of the upper tier of plates, and is of wrought-iron chequered plates, supported on cast-iron girders, prepared to receive the column carrying the optical apparatus. The top flange of the tower is constructed to allow the feet of the lantern standards to pass down between the flanges of the plates, to which they are secured by a cottar and bolt to each standard. The standards are of wrought iron, 3 inches deep by $\frac{1}{2}$ inch thick at the centre, but enlarged at the top and bottom to $1\frac{1}{4}$ inch wide, to afford extra strength and enable the necessary connections to be made.

On account of the thinness of the standards, the plate glass, $\frac{3}{8}$ inch in thickness, is fitted to the lantern without any metal separation between the panes, and semiholes were cut in each pane, with a revolving iron disc and emery, for the gun-metal screws to pass through that held the gilding-metal strips to secure the glass. The top and bottom sills are of gun metal. The roof is of copper, 3 lbs. to the square foot, and was made in one piece, covering strips being soldered and rivetted to each joint.

The optical apparatus is a Fourth Order fixed for 270°, with a metallic reflector for the remaining 90° similar to Fig. 30. A reservoir lamp is placed on the top of the apparatus, with the damper tube passing through an aperture in the centre, and the feed pipe for the burner passes down the side of one of the racks in the non-illuminated arc, and is furnished with a stopcock and regulator.

The Sixth Order holophote placed in the tower is shown in Fig.

56, Plate 6. It is employed to collect all the light from its lamp into one beam of parallel rays, which is thrown across the entrance to the harbour to illuminate the beacon. A reservoir lamp is used, similar to that for the Fourth Order, but having a much smaller burner. (See the sectional elevation.) The beacon consists of a base plate, with four cast-iron standards of open work bolted to it, so as to form a support for the optical apparatus, and to carry a trimming stage. The lantern is made of cast-iron plates, with a window (opening in halves) to allow the light from the holophote to enter, and at each of the adjoining corners is fitted a pane of curved glass to allow the light to escape after it has been acted upon by the vertical prisms. Suitable openings are provided on three sides to allow of cleaning the interior, all being rendered weather-tight by gun-metal blank windows. The optical portion consists of two sets of right-angled prisms *a*, placed V-shaped, the included angle being 90°. These prisms split the light falling upon them into two beams of parallel rays going in opposite directions, each ray being bent through 90°. The second sets of prisms *b* receive the parallel rays from the first two sets *a*, and each brings its light to a focus at *c*, from whence the light diverges through an angle of 90° on each side of the apparatus, making the total angle illuminated 180°. The effect produced is the same as if a small lamp were placed in the beacon, illuminating the 180° of the sea next to the tower. It is not thought objectionable, but rather advantageous, that the two foci in the beacon are some distance apart, as the angle is thereby diminished, through which an obscuration of the beacon is caused by the body of the tower.

In the original design five rectangular prisms were shown on each side, in all respects similar to each other; but when the apparatus came to be tried, it was found that there was a fine band of colour, opposite the junction of the first and second rectangular prisms, in the second refractor *d*. This defect was remedied by diminishing the size of the first two rectangular prisms, and adding another small one between the two, as at *e*, so that the joints of the rectangular prisms came opposite the dark part of the refractors.

On account of the distance that the beacon is placed from the holophote, 300 feet, a quantity of light is lost through the divergence of the holophote due to the size of the oil flame. For a similar reason the divergence of the beacon is small, but ample for what is required, as it is placed low, and a range of only about a mile is required.

The Paper is illustrated by a series of diagrams, as well as by the reduced drawings, from which Plates 1 to 6 have been engraved.

APPENDIX.

DESCRIPTION of MR. ALAN BREBNER'S REFRACTION PROTRACTOR, for Glass with refractive index of 1·51 (Plate 7).

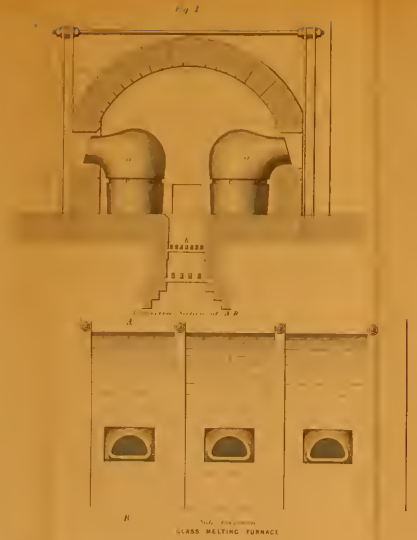
The Instrument consists of two parts: the lower limb L H N G which forms a complete circle, and the upper limb A K B which is a semicircle. The lower limb is made to move easily round a centre on the upper limb, which is perforated and filled in with glass, and two axial cross lines are drawn on the glass. The under side of this centre part rests on the table, and is fitted with three points, which penetrate the table and keep the upper limb from turning; while the lower one, which is next the table, turns freely. One half of the lower limb is divided into degrees, and is numbered from the middle towards each side, and also from each side towards the middle; the opposite half is so divided as to make the sines of the opposing angles have a ratio of 1·51 to 1.

To use the Instrument.

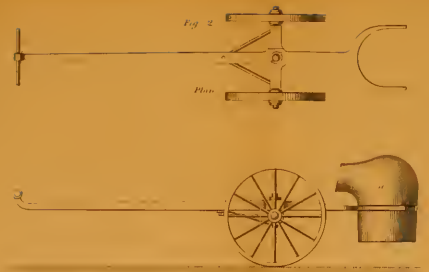
For finding the path of a ray through a piece of glass: Let G H represent the surface of a piece of glass, and F C any ray falling upon it. Read off the angle from the perpendicular L C N, and mark off the same reading from N towards S. In the figure (Plate 7), the ray F C, which cuts the limb at 19½°, will pass through the glass in the direction C P, which is 19½° from N.

For constructing a totally reflecting Prism.

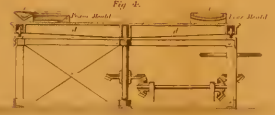
Suppose it is required to construct a prism, which shall reflect into a parallel beam, in a required direction, the angle of light C F M, emanating from a flame F. The point F, the apex of the prism C, and the required direction C T being fixed, place the centre of the instrument on C, with the axis of the upper limb A B coinciding with the line of the emergent ray T C, and keep the upper limb in this position, by slight pressure, while the instrument is being used. Now move round the lower limb, bringing the perpendicular C L towards the ray F C, until the angle between L and the ray F C and its complement (which to save performing the deduction mentally is marked above it) reads the same as the angle from A towards K, and the angle from N towards S: for example, in the figure the ray F C cuts at 19½°, the complement of which is 70½°, and 19½° from N towards S coincides with 70½° from A towards K, and in no other position of the two limbs can this occur. G H and C P then fix the two sides of the prism, and the angle T C P will be equal to the angle F C H. To determine the reflecting side, draw the dotted line E C parallel to F M, observe where it cuts the lower limb at X, viz., 10¾°, and mark off the same reading at Y. Bisect the angle Y C H at the point *y*, and from M draw the line M W perpendicular to the bisecting line, until it meets the medial bisecting line C R; then bisect the angle P C H at the point *h*, and from the point W draw the line *p* W perpendicular to the bisecting line. *p* W and W M are the tangents to the curve *p* O M, and all the rays falling upon the side C M from the focus F will be refracted so as to fall on the side M O *p*, at such an angle as to ensure their being reflected in a direction parallel to M C, and will consequently be refracted at the side C *p*, so as to emerge from it parallel to C T and *p* O.



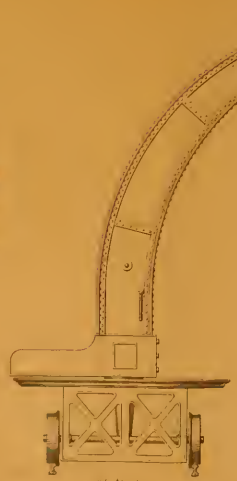
GLASS MELTING FURNACE



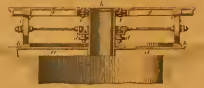
POT SETTING MACHINE.



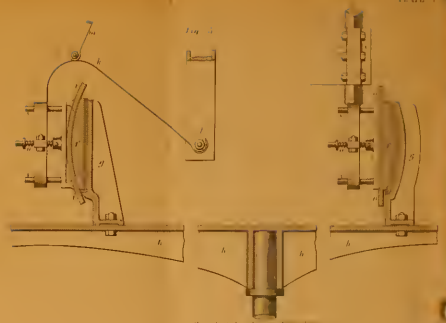
CASTING TABLE.

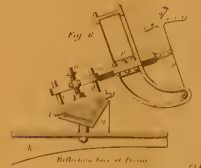


PORTABLE CRANE

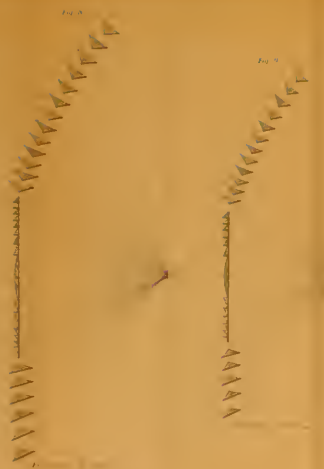


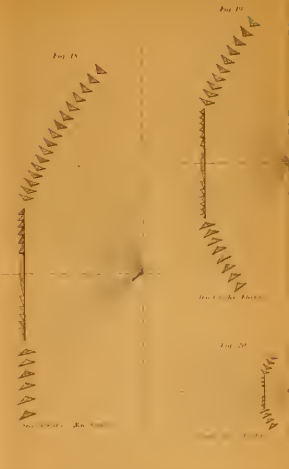
ERECTING TABLE



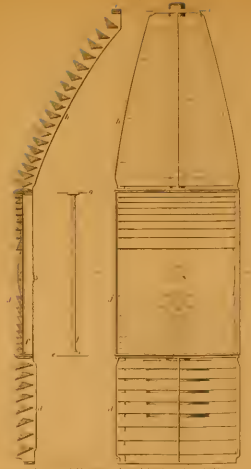


GLASS GRINDING

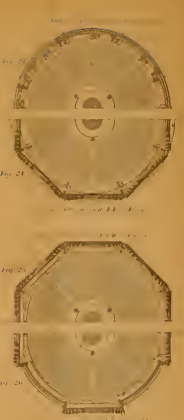


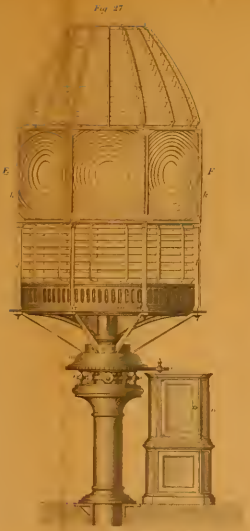


SECTIONS OF GLASS USED IN LIGHTHOUSE OPTICAL APPARATUS.

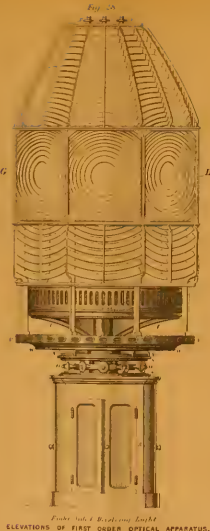


FIRST ORDER OPTICAL APPARATUS



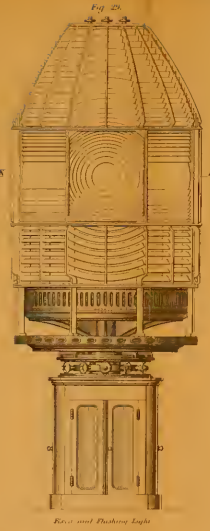


Fixed Lenticular Apparatus of First Order.



Fixed with a Revolving Light

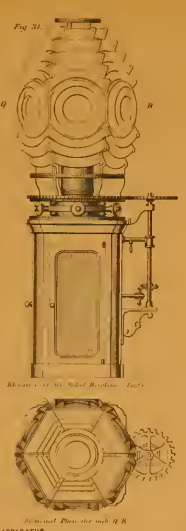
ELEVATIONS OF FIRST ORDER OPTICAL APPARATUS.



Revolving Light

Fixed Lens Vertical Section through the axis M N

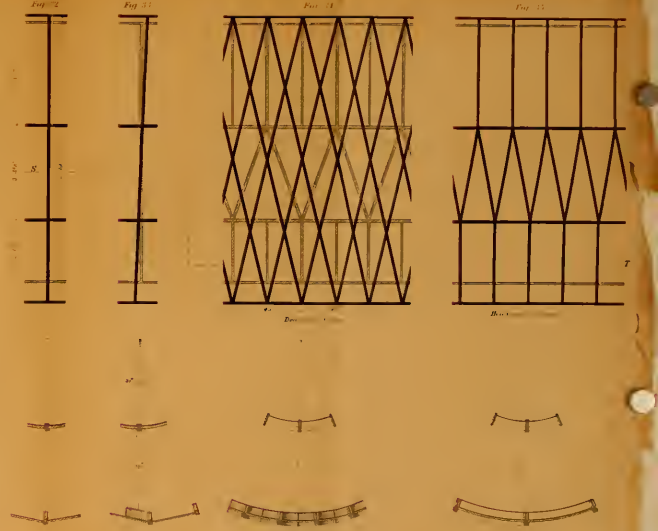
Horizontal Plan through O P



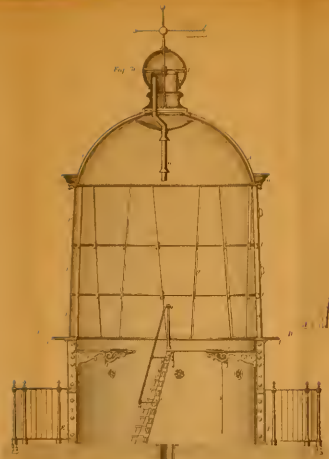
Elevation of the Fixed Revolving Light

Horizontal Plan through Q R

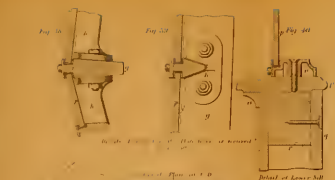
FOURTH ORDER OPTICAL APPARATUS.

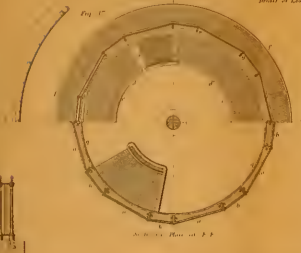


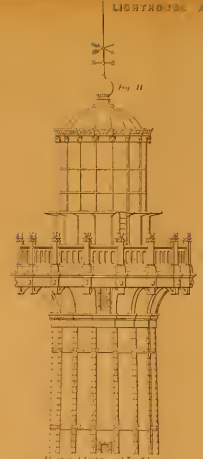
DIAGRAMS INDICATING THE OBSTRUCTION OF LIGHT IN FIRST ORDER APPARATUS, BY THE FRAMING OF THE LIGHT AND LANTERN.



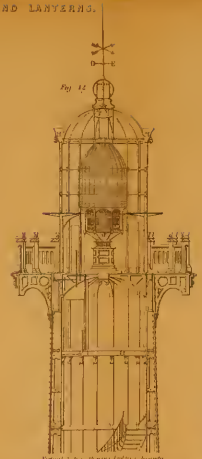
LANTERN WITH INCLINED FRAMING. (FIRST ORDER.)

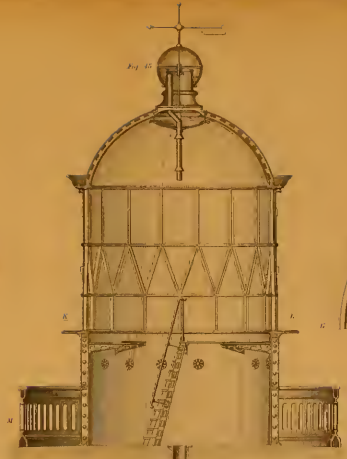




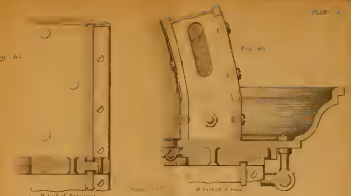


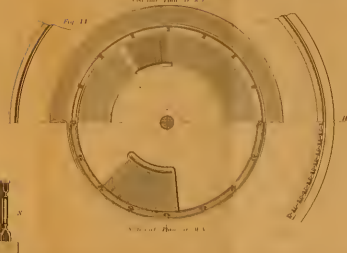
ROCHES-DOUVRES LIGHTHOUSE

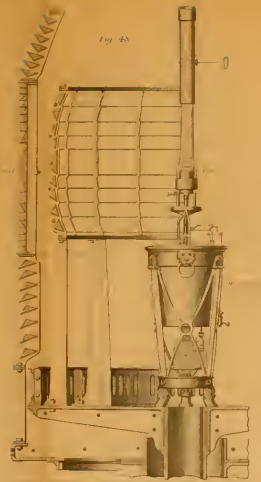




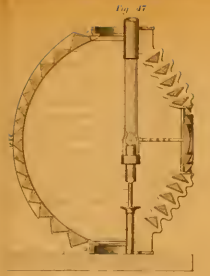
LANTERN WITH FRAMING ON HENDERSONS SYSTEM.

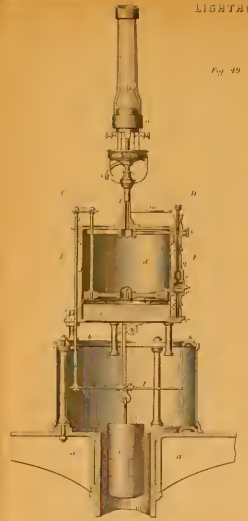




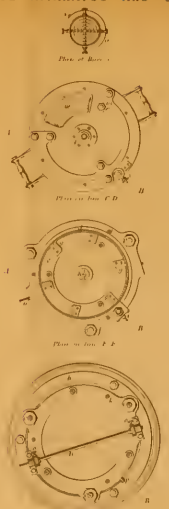


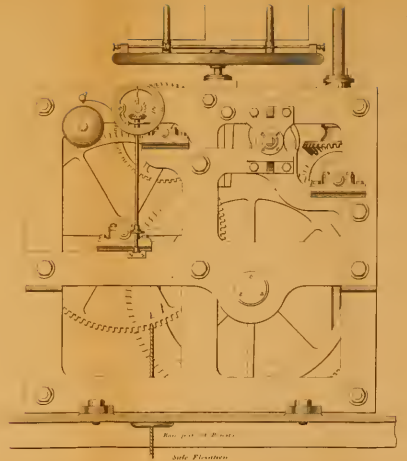
CATADIOPTRIC MIRRORS.





PRESSURE LAMP.





FIRST ORDER CLOCKWORK WITH SELF-ACTING MAINTAINING POWER DURING THE WINDING UP.

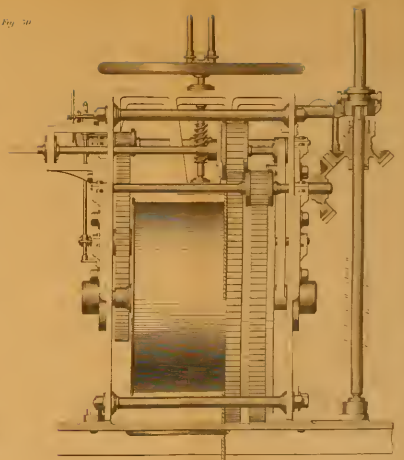
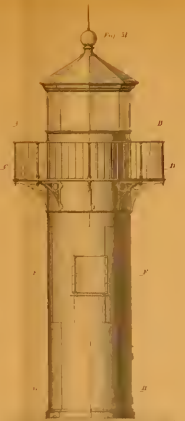
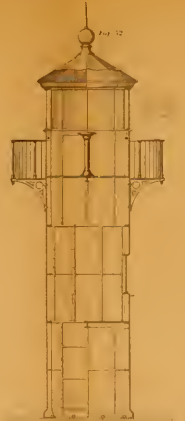
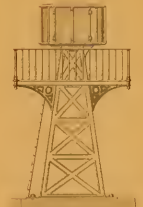


CHART OF ODESSA HARBOUR

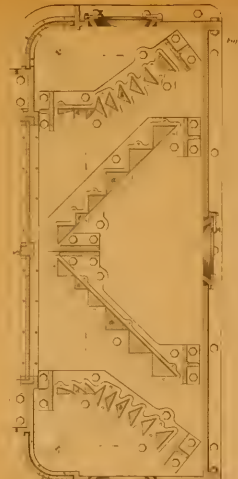


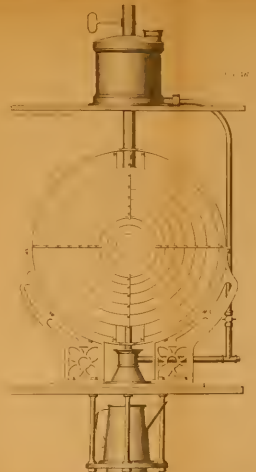


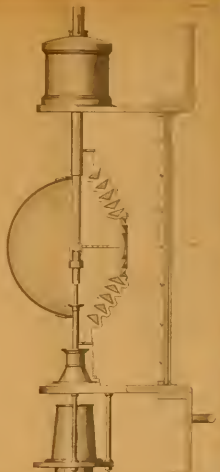
LIGHTHOUSE AND APPARENT LIGHT AT ODESSA HARBOUR (PRATIQUE PORT)



APPARENT LIGHT ON POTAPOUSKI MOLE



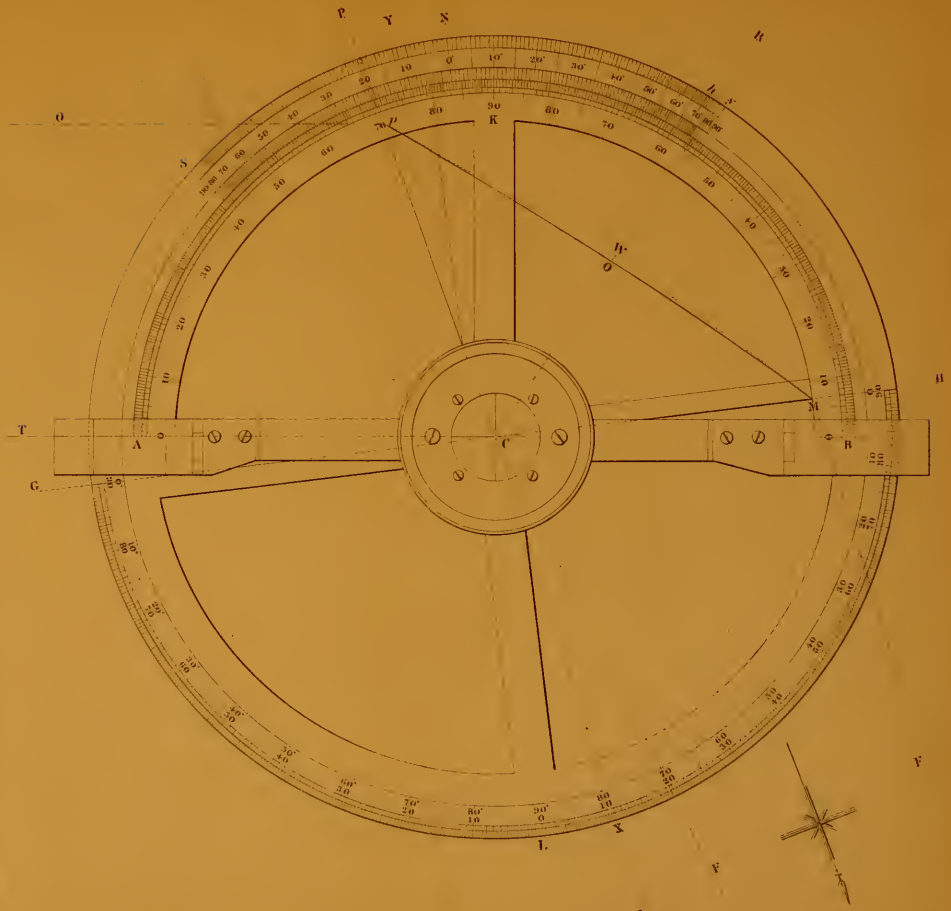




DETAILS OF HOLOPHOTE PLACED IN TOWER (SIXTH ORDER

LIGHTHOUSE APPARATUS AND LANTERNS.

Mr ALAN BREBNER'S REFRACTION PROTRACTOR, FOR GLASS WITH REFRACTIVE INDEX OF 1·51.



Mr. Henderson said he had been anxious to furnish some detailed particulars as to the construction of lighthouse apparatus and lanterns, inasmuch as the Paper by Mr. Chance treated exclusively of the optical portion of the subject: the two Papers together might, he thought, be regarded as illustrating the best lighthouse practice of the day. He had not brought forward the system of lights constructed of metallic reflectors, because there were many published treatises on that subject, among which might be mentioned the one by M. Léonce Reynaud. There were at present four different varieties of lanterns in use in this country, each of which had its own supporters. In arriving at an opinion as to which lantern was the most advantageous, he thought economy of light and money were both elements of great importance.

Mr. Redman directed attention to the fact that the use of lenses for lighthouse purposes was of English origin. The lenses originally employed were of one piece of glass for the entire height, but the thickness of the lens, and the consequent absorption of light were so great, that lenses of that kind were abandoned. Buffon first proposed the grinding of the lenses in steps, or concentric rings, to overcome this objection; but the difficulty of shaping a solid piece of glass to this form led to its abandonment. Condorcet, in 1773, suggested the 'building up' of the lens in separate pieces. Sir David Brewster also, in 1811, and Fresnel, in 1822, proposed the same method, and the latter first applied it practically, and it was generally assumed without previous knowledge of what had been done by his predecessors. As far back as the year 1827 experiments were made by the Trinity House with Sir David Brewster's lenses, which were abandoned; so that in reality the present system of French lights was, to a great extent, of English origin. He might add that lenses were first used on the south coast of England sixty years or seventy years back.

Mr. Wilfrid Airy remarked that, according to the proportions given by the Author, the glass, as made by the French and the English manufacturers, differed materially in quality. In the French article there was a preponderance of lime over soda, while in the English glass the soda was in excess of the lime. He could not but think that a very different glass must result from such dissimilar admixtures, and he would ask whether, in addition to the difference in the refractive index, the one was not harder than the other, and also unlike in colour? It was stated that a margin of $\frac{1}{8}$ inch was allowed round the lens as it was cast. As the grinding of glass was a laborious process, he thought it would be desirable, if possible, to reduce that margin, unless it was necessary, from the purity of the glass being injured to that depth from contact with the mould, or in consequence of inaccuracy in the casting, so as to allow of the grinding it up to the true shape.

Admiral Collinson considered the Author's lantern adapted to show the light on the horizon, but that from its form it was likely to obstruct the light between the line of the horizon and the light-house, a point of importance where lighthouses were placed at a great elevation. In the course of the present year the Trinity House had made experiments to ascertain the relative advantages of petroleum and colza oil. It was found that paraffin oil did not give so much light as colza oil, that it caused the wicks to char, and that there was a difficulty in getting up the flame again when a four-wick First Order or a three-wick Second Order light was trimmed: the use of paraffin was consequently abandoned until a description of wick adapted to its consumption was introduced. A few years ago a sample of oil sent to the Trinity House was tested and approved; but after the oil was issued, complaints came in from the lighthouse-keepers that the lights could not be maintained; and in corroboration a representation was made by the Captain of one of H.M.'s ships, that the Edystone light was on one occasion not visible for fifteen minutes. The Trinity House authorities had some difficulty in discovering how the oil was adulterated; eventually it was found not to stand the test of temperature, the sample oil freezing at a lower temperature than the oil which was delivered. The contract was declared void, and the oil was returned. The Author had suggested the use of the dioptric apparatus on floating light-ships. The Trinity House would gladly adopt such a combination, if it were possible; but hitherto the difficulty of trimming the lamp in a gale of wind was so great, owing to the motion of the ship, that it could not be rendered practically efficient. Mr. Douglass had a proposition before the Trinity Board to substitute iron for wooden masts, by which the ventilation and supply of air for the lamps would be greatly improved. But at present the Board were unhesitatingly of opinion, that the catoptric system was better suited for the service of the floating lights than the dioptric. Such was the perfection arrived at, in consequence of the experience gained by the Trinity House, that in a period of seven or eight years only one vessel had drifted from her moorings.

The different character of the lights was perhaps the most important point of all. Sea-lights were multiplying so rapidly in every direction that it was difficult to distinguish one from the other, notwithstanding the use of red and green-coloured glass and that some lights were fixed while others revolved. The Author of the Paper was present when the green light was tested, under favourable circumstances, in the case of a Second Order light at Lowestoft; the green light on a hazy evening was then so obscured at a distance of $2\frac{1}{2}$ miles, that it was found necessary to replace it by a bright light. Green lights must therefore be regarded as available only for very short distances. In red lights, no doubt, many rays were lost;

however, at the Rock Lighthouse, at Liverpool, by the addition of more burners to the catoptric apparatus, the red light had been brought on an equality with the white light. It was two years since he had visited that light, but it had been subsequently altered and improved, and he was informed by the light-keepers at Orme's Head, that on a foggy night the light first seen was the red. This was a point of importance, because, recently, the Master of one of H.M.'s ships, in coming up the Channel, and sighting Ushant, where the light had two white faces and one red one, had been unable to make out the red face at all, so that it would appear that, under certain conditions of weather, the red light was obscured; thus not only was the distinctive character of the colour of the light in question destroyed, but the duration of the flash as a revolving light was altered. The Trinity Board intended to establish a revolving light on the Wolf Rock in that neighbourhood on the dioptric system; and Mr. Chance had so arranged the flashes that the red light and the white were of equal intensity. The importance of these distinctions was shown in the mistakes made by uneducated people. The year before last a representation was sent in to the Board of Trade, that a man had mistaken the Galloper Light for the Leman and Ower Light. The two light vessels were 90 miles apart, and both carried two lights, the one a revolving and a fixed light, and the other two fixed lights: yet this man explained, as the reason for his ship going ashore, that he mistook the one light for the other. In another instance the Captain of a small Danish schooner, bound for London, sailed past Harwich up the River Stour, mistaking Landguard Fort and Harwich for Tilbury and Gravesend. Hence it would be inexpedient to establish any lights but such as could be perfectly understood by the simplest people. The question of fog-signals was intimately connected with light-house efficiency, and was, in his opinion, of equal importance with the subject now under consideration. He trusted, therefore, that, on some other occasion, it might be brought forward for discussion.

Mr. James N. Douglass, Engineer to the Trinity House, said, the various forms and sizes of dioptric apparatus in use for oil-lamps had been fully described in the Paper; but a question of great importance at the present moment was the description of apparatus to be employed in future with the electric light. The dioptric apparatus at Dungeness and at Cap le Havre belonged to the Sixth Order; and experiments made by the Trinity House at the Paris Exhibition of 1867, with a Third Order apparatus for a fixed light, seemed to point to this, or even a larger apparatus, as the most efficient instrument for fully developing and maintaining a steady electric light. This matter was, however, still the subject of further experiment and practical test by the Trinity

House, and would doubtless receive at the hands of their scientific adviser, Professor Tyndall, the fullest investigation.

Petroleum had been referred to by the Author as better suited for lamps than the colza oil at present used for lighthouse illumination; but this only applied to small single-wick lamps. When compared with the three and four concentric-wick oil-lamps of the Second and First Order lights the result was not so good. Experiments had recently been made by the Trinity House with the First Order petroleum lamp of Captain Doty—one of the best that had yet appeared; but the luminous intensity of the light was found to be only three-fourths that of the oil-lamp of the same size. He thought, however, much was yet to be accomplished with petroleum for the illumination of lighthouses. In his observations he would distinguish the framing of the lantern from that of the dioptric apparatus, by giving the latter its technical title of armature. The cylindrical form for the lantern was doubtless the best, both optically and for strength, and the framing having the greatest inclination would intercept a minimum of the vertically elongated beam of light sent from the dioptric apparatus. This question of inclination also applied to the armature of the apparatus, and hence it was of much greater importance as regarded obstruction of light than in the framing of the lantern, being so much nearer to the radiant. Fig. 1, page 39, showed a development of 180° of the helical framing of his cylindrical lantern, with the obscuration due to the armature of the apparatus on the same plane. The image of the flame was shown by dotted lines.

In the diagonally framed lantern of Messrs. Stevenson, and the cylindrical vertically framed Trinity House lantern, the interception of light had been reduced to a minimum, and the interception was almost uniformly distributed over the illuminated area of the sea surface. In Messrs. Stevenson's lantern the maximum interception of the transmited light from an apparatus for fixed light was 4·9, the minimum 4·0, and the mean 4·45 per cent. In the Trinity House lantern the maximum interception was 3·5, the minimum 2·9, and the mean 3·2 per cent., not 6·8 per cent., as stated in the Paper. The comparative advantages of the lighthouse lanterns adopted by the Trinity House and by the Commissioners of Northern Lights had lately been under the consideration of the Board of Trade, and the subject had been investigated by Professor Tyndall, Messrs. Stevenson, and himself.[1]

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[1] Mr. Douglass presented to the Institution, for the Library, a copy of the "Correspondence relative to the comparative advantages of the Lighthouse Lanterns adopted by the Corporation of the Trinity House and the Commissioners of Northern Lighthouses." 1867–8. London, 1868. [Inst. C.E. Tracts, fol., vol. xi.] —Sec. Inst. C.E.

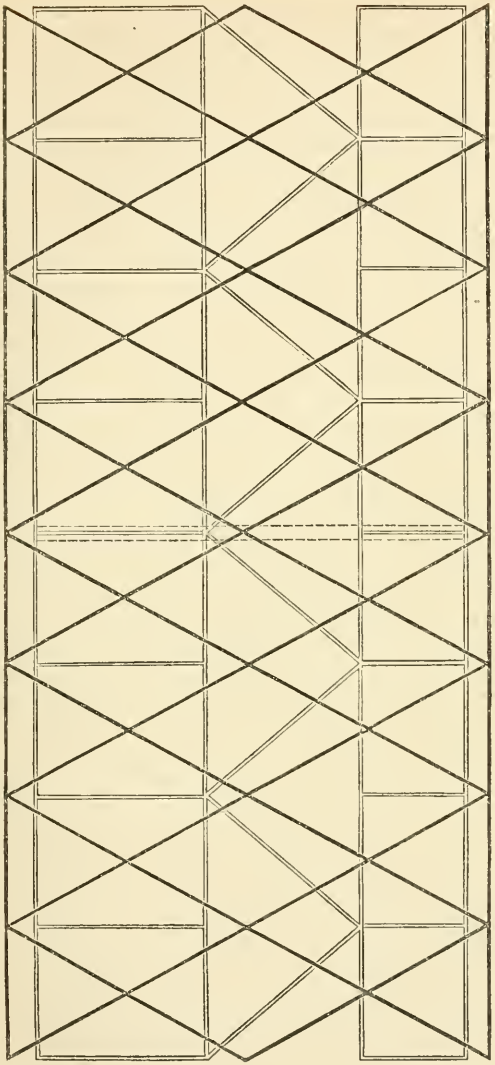


Fig. 1.

Scale 4 feet to 1 inch.

The Author of the Paper proposed a lantern with a new arrangement of framing, as shown in Plate 4, Fig. 43, having partly vertical and partly inclined framing; all of which was to coincide optically with the armature of the dioptric apparatus. Now, with the heavy vertical armature of the early dioptric apparatus, where on the bearing of each vertical portion of the arma-

ture 50 per cent. of light was in some cases intercepted, it was doubtless the best arrangement to make the framing of the lantern coincide optically with the armature of the apparatus; but with the improved lanterns of Messrs. Stevenson, or of the Trinity House, it would be a decided step backwards. As the lenticular belt of the dioptric apparatus was found to have an illuminating value of 70 per cent. of the whole instrument, it was evident that the least interception of light was obtained by the greatest inclination of the armature of the refracting panels of the instrument. In the latest English and Scotch lights the inclination was about 21°, and the interception of the transmitted light was only 4·5 per cent., and there was reason to expect that Messrs. Chance would succeed, by giving greater inclination to the framing of the armature, and by making it thinner, in further reducing the interception of light. The above interception, added to the maximum interception due to the framing of the Trinity House lantern, gave 8·0 per cent. as the aggregate maximum interception of the transmitted light due to the armature of the apparatus and the framing of the lantern. But to attain optical coincidence between the armature of even the present apparatus and the framing of a lantern, the inclination of the framing would be so much increased, owing to increased radius, as to render it beyond the limit of safety for the structure. The Author therefore proposed a safer inclination for the lantern framing (Plate 4, Fig. 43), and by arranging the armature of the dioptric apparatus to coincide optically with it, the latter attained an inclination of only 11° (Plate 2, Fig. 22). And the interception with this armature was found to be 8·6 per cent. of the transmitted light, or nearly double that of the dioptric apparatus at present in use. He would further add that the form of lantern framing proposed was very imperfect, as no diagonals were carried down to the base of the structure. This want of bracing in many vertically framed lanterns caused straining, and consequent loosening, and frequent breakage of the glass during storms. He might remark that there had been no fracture of the glass with the cylindrical Trinity House lanterns, and one of the fifteen lanterns now erected had been in position more than two years. The two horizontal bars proposed were objectionable: these bars must be placed optically coincident with the horizontal armature of the apparatus, or they would further intercept the light. Besides, horizontal bars were more liable to cause leakage than the other portion of the framing, and there was the additional objection that during snow storms snow would accumulate more rapidly upon them than upon inclined bars, to the detriment of the light. In the Trinity House lantern it was, to use the words of the late Professor Faraday, "nearly a matter of indifference as regards

shadow how the uprights of the optical apparatus were placed in relation to such a lantern." This was of great importance to the lighthouse engineer as it left him free to readjust the dioptric apparatus to meet any altered conditions of the local navigation, or to change the size, or improve the form of the apparatus without interfering with the construction of the lantern.

Although the Author was of opinion that the Trinity House lantern was expensive, from the amount of workmanship of a costly class, and from the glass cut to waste, he could state that in the fifteen Trinity House lanterns constructed from his designs a high standard of material and workmanship had been insisted on, especially as regarded the glass, and it was the opinion of Professor Tyndall that even greater optical perfection would yet be obtained in the glass portion of the structure. The average actual cost of six First Order 14-feet lanterns, fixed complete at English lighthouses, had been £1,244 13*s.* 2*d.*, and he was sure that cost would compare favourably with that of any similar work either in this country or on the Continent.

Mr. William Parkes remarked that, before the dioptric system was introduced, the only lantern in existence had upright standards and rectangular framing. That answered the purpose tolerably well with the old catoptric or reflecting lights, with several lamps distributed over a considerable width within the lantern. But as in the dioptric apparatus there was a single central lamp, the light from which was refracted into a narrow vertical line of illumination, it was evident that, if an upright standard came between the spectator and that line, a large proportion of light would be obscured. On the introduction of the dioptric system, the question of the lantern framing was taken up, nearly simultaneously, by the late Mr. James Walker (Past President Inst. C.E.) for the Trinity House, and by the late Mr. Alan Stevenson (M. Inst. C.E.) for the Commissioners of Northern Lights. Mr. Stevenson arrived at a solution of the question not very different from that to which Mr. Douglass had come; but the construction was dissimilar. The main difference, so far as obscuration was concerned, was this—Mr. Stevenson introduced certain horizontal members into the framing which Mr. Douglass had done away with. Mr. Walker's lantern had inclined, but not altogether diagonal, standards, like those of Mr. Stevenson and of Mr. Douglass. Mr. Parkes had adopted a form of framing similar to Mr. Walker's, which had the advantage of simplicity of construction and facility in erection. He had estimated the obstruction caused by the different lanterns, and had found the proportion of the area of opaque framing to that of the whole glazed surface was 5·7 per cent. in his lantern; but that was not equally distributed round the circle. The circle was divided into twenty-four arcs,

alternately of 13° and 17°. In the arcs of 13° the obscuration was about 11 per cent.: in the arcs of 17° it was about 2 per cent. The merit or demerit of a lantern was to be measured by the amount of obscuration in the most obscured part, and that in his lantern was 11 per cent. In Mr. Douglass' lantern, and he believed also in Mr. Stevenson's, it was 6·8 per cent. Mr. Douglass said it was only 3·2 per cent. Probably this result was obtained by a different method of calculating the obscuration; but if this method, whatever it might be, were equally applicable to both, the proportion of obscuration in the one lantern to that in the other must remain about the same; so that the maximum obscurations in Mr. Parkes' lantern to the nearly constant obscuration in Mr. Douglass' would be in the proportion of about 11 to 7. No doubt Mr. Douglass' lanterns were in theory superior in that proportion; but he believed that, up to the present time, Mr. Douglass had not succeeded in getting them made at so low a price as those on Mr. Walker's system, and that they could not be erected on the lighthouse towers in so short a time. The question was whether these disadvantages were a sufficient set-off against the theoretical superiority of Mr. Douglass' lantern. He believed Professor Faraday's report, with regard to the obscuration of Mr. Douglass' helical lantern, was, that practically there was no shadow. If this were the case with a calculated obscuration of nearly 7 per cent., it could not be very serious with a calculated obscuration of 11 per cent., and he therefore doubted whether there was sufficient inducement to spend extra money and time upon these lanterns, which were complicated in construction and took a long time to erect. The time required for the erection of the lantern on a lighthouse was of importance, as it involved keeping up an expensive establishment for very little work, and it was an object to do the work in four or five weeks instead of as many months. It ought further to be stated, that the advantage in Mr. Douglass' lantern applied only to fixed lights, which showed a thin vertical line of illumination. In revolving lights, the illuminated column having a considerable width, the obscuration caused by the framing was of less importance; but in those cases the advantage, such as it was, would be with Mr. Walker's lanterns, as the arcs of small obscuration would have to be taken into account, as well as those in which the obscuration was greater.

Mr. W. H. Cutler considered the magneto-electric light, of all known kinds of light, was the most appropriate for lighthouse purposes. To work the magneto-electric light apparatus a small engine was required; and if the light went out, or there was such a thick fog that it was of no use, the engine would be available to work a fog horn, a specimen of which was exhibited at the Paris

Exhibition of 1867. Reports had been received that the sound, which was produced by vibration, could be heard at a distance of 16 miles. Two single-acting air-pumps, connected by three oval wheels, threw a continuous stream of air into an air vessel, at a pressure of about three atmospheres: thence it was taken, as required, through a small square metal box to the horn. The metal box had a partition in it, and through the partition there was a slot, about 6 inches long and $\frac{3}{4}$ inch wide. Over the slot, and firmly secured at one end, was a tongue of brass, rather more than $\frac{3}{16}$ inch thick. The compressed air rushing past this tongue caused it to vibrate, and produced the sound, which could be varied by moving a triangular slide along the metal tongue. He thought the electric light apparatus and the fog horn should be supplied to all lighthouses, so that they might be useful in foggy as well as during clear weather.

Captain Owen observed that the Trinity House had adopted an efficient horn, which was used when the lights were obscured by fog; but it was not intended to replace the lights when they accidentally went out. The late Professor Faraday once said at the Trinity House, that inasmuch as the sun itself was unable to penetrate a dense fog, so no electric or any other light could be expected to do so. The fog horn was there as a warning when the light was obscured; and although the electric light answered very well, even it could not penetrate a fog. With regard to the lanterns which had been referred to, he was at the Trinity House when Mr. Walker's lantern was introduced, but it was not better than that which was then in use.

Dr. Gladstone thought the arrangement of the framework of the panels of considerable importance, as the fear of the diminution of light by upright frames was by no means an imaginary one. Once when he was passing the fixed light at Berwick it was supposed that something had got in the way of the light, or that it had gone out, although no vessel was visible between him and the lighthouse. It appeared afterwards, on inspecting the apparatus, that a bar intercepted the light at the point of observation, so that practically the light was for the time extinguished. That was an extreme instance, which, he believed, would not occur with any Trinity House apparatus. He had seen in one of the lights in Scotland, a contrivance by Mr. Stevenson for gathering up the rays and sending them in a particular direction. The optical apparatus was excellent, but, owing to an upright bar in the lantern, the object of the arrangement of the prism was in a great measure defeated. As far as he was aware, there was only one apparent light on the British coast, that at Stornoway, in the Hebrides, where a small contrivance on the top of a rock reflected the light thrown from the shore by means of a mirror; but it was not very

successful. At Odessa, he believed the light was a dioptric, which was best suited to the purpose, as it condensed a larger portion of light. He should like to hear whether that description of light was successful beyond the distance of 1 mile; because if that were the case, there were many places on the English coast where an apparent light would be of service. Though pleased to hear of the success which had attended the efforts of the Trinity House to bring the luminous effect of the red light to a par with that of the white, especially as it enabled alternate red and white to be better shown as a distinctive light, there were certain disadvantages connected with the use of any coloured light. At present there was no way of colouring light without a great number of its rays being absorbed. Then supposing the red and the white lights to be of apparently the same strength, if a mist came on the red light would be the stronger of the two, because fog absorbed the blue and green rays; and there might be other meteorological conditions which produced peculiar effects. Again, many people were colour blind, and could not distinguish between white light and red light. He knew a person who could only distinguish the difference between a revolving red and white light by describing the red light to be duller than the white; and such instances of colour blindness were far from uncommon. At the same time he should be sorry if the beautiful red and white revolving lights now in use were abolished, on account of their importance as distinctive lights. The question of fog signals deserved a great deal of consideration; but it was beyond the special subject which had been introduced in the Paper.

Mr. Beazeley remarked that Mr. Parkes had calculated the amount of opacity (or obstruction of the framing) of a lantern, by taking the total area of the standards and the total area of the face of the lantern, and deducing a percentage from those data. He considered that was a mistaken way of treating the question. In a dioptric apparatus the light was concentrated into a narrow column, or elongated image of the flame, with which alone the mariner had to deal; and all that had to be taken into account, in estimating the percentage of obstruction in any lantern, was the amount of the framing which could at any one time come across that narrow bar of light. No man's eye could at one time take in the whole light diffused over an arc of 13°; and, the image of the light being a narrow column, the calculation of obstruction diffused over the whole illuminated arc was beside the question.

With reference to the greater length of time required to erect the Trinity House lanterns, as compared with those of the ordinary pattern, he would remark that it had been sought to obtain the utmost amount of rigidity by riveting instead of screwing the framing together. The latter could be done more quickly than

riveting, but it did not produce the same amount of homogeneity in the structure, and did not bring the surfaces of the metal together with the same certainty.

Mr. T. A. Rochussen stated, that when Mr. Douglass' lantern was in course of conception, he had been asked whether it would be possible to produce sections of the sash and sill bars of steel sufficiently strong to bear the weight of the roof, and to withstand the force of the wind; and at the same time to weld together in such a form, and at such short angles as were represented in Fig. 1, p. 39. As an ironmaster there was little to be got from it; but regarding it from a sailor's point of view, and knowing the importance of good lights on all coasts, he had the required section cut, and the steel rolled. That sash could be applied either for a railway station roof, or any other roof of large size; and thus it might turn out valuable in a way which Mr. Douglass perhaps did not anticipate. It was a question whether the material should be cast steel of great elasticity, or puddled steel easily welded. Knowing that gun-metal framing was largely adopted, he tried the comparative strength of the different metals by hydraulic pressure, and found that strong fibrous iron burst under a pressure of thirty-four atmospheres at an angle of 160°; that gun-metal gave way at an angle of 160°, with a pressure of thirty-seven atmospheres; that fine grain iron would bear thirty-nine atmospheres, and simply show a slight crack in the skin, at an angle of 165°; while the steel at an angle of 165° resisted a pressure of fifty-four atmospheres without cracking. He would take the opportunity, as an old sailor, to find fault with the perfection now sought to be obtained in these lights. Every ray of light was reflected by the lens so completely to the horizon, that the light of a candle held over the flame would not project a cone of shadow on the roof of the lantern. Now of the various elements that guided navigators one was an upward glare of light in the sky. In the hazy climate of northern countries, a vessel often sailed through a zone of low dense fog, and a light which would then be obscured, though close at hand, might be so arranged as to throw some rays upwards, and reflect a glare from the clouds. The loss of light by a cone of shadow of between 3° and 7° was of little importance: but a beam of light of 4° would be a great advantage were it visible only as a glimmer over a topsail-yard, when the light itself could perhaps not be seen from the lower yard.

Mr. Henderson, in reply, observed that he had not gone into the question of the electric light any further than to give the two sections of apparatus made for the Trinity House. The smaller, or Sixth Order, was constructed with a helical intermediate rack, extending over the upper and lower prisms as well as the lenses. This, the first application of the kind, had since been

adopted by the French. The larger one, or Third Order, was constructed on his plan of excentering the joints of the upper and lower panels of reflectors, with inclined framing for the lens panels, similar to that shown for a First Order fixed light in Fig. 22, Plate 2. It was questionable if the Third Order was the most suitable size for the electric light. A Second Order would be better for the speedy admission of an oil lamp into the focus, in the event of an accident happening to any part of the electric light-producing apparatus.

He agreed with Mr. Douglass that the circular form of glazing was the best, but he was at variance with him in respect to the arrangement of the framing. In a First Order, the height of the apparatus giving forth light was 8 feet $8\frac{1}{2}$ inches; 5 feet $1\frac{1}{8}$ inch being above the focal plane, and 3 feet $7\frac{3}{8}$ inches below it. If divergence were neglected, there would remain to be considered a portion of the glazing of the lantern of only 8 feet $8\frac{1}{2}$ inches in height. The diameter of the Trinity House lantern, to the inner edge of the framing, was 13 feet $8\frac{1}{2}$ inches, giving an area of light of 3·1416 × 13 feet $8\frac{1}{2}$ inches × 8 feet $8\frac{1}{2}$ inches, equal to 54,005 square inches. There were thirty-two inclined bars in the lantern, each 10 feet $2\frac{1}{2}$ inches long, and $\frac{5}{16}$ inch thick, so that an area of 3,675 square inches of the light of the lantern was obscured, equal to 6·8 per cent., or to a horizontal band of obscuration 7·1 inches deep carried all round. In comparing the improved system with the above, the same diameter must, of course, be taken, then the obscuration would be as follows :—

			Sq. Inches.
Opposite upper prisms	sixteen bars 3 ft. $5\frac{7}{16}$ in. long	× $\frac{15}{16}$ in. thick	= 621·56
„ lenses	thirty-two „ 3 ft. $6\frac{1}{2}$ in. „	× $\frac{15}{16}$ in. „	= 1275·00
„ lower prisms	sixteen „ 1 ft. $11\frac{11}{16}$ in. „	× $\frac{15}{16}$ in. „	= 355·31
		Area in square inches of total obscuration	= 2251·87

which was equal to 4·17 per cent.—a difference of 2·63 per cent. in favour of the latter system simply considered as a lantern framing without reference to the apparatus. In the optical apparatus at present used by the Trinity House 4·5 per cent. of the surface of the glass was obscured by the framing of the apparatus, and this latter obscuration was in addition to that caused by the lantern framing, as the two did not coincide, Fig. 34, Plate 3. In the improved system, the obstruction of the apparatus might remain at 4·5 per cent.; but every part covered, or coincided optically with, a corresponding portion of the lantern framing, so that the total loss, when the triangular system of supports to carry the upper cupola was complete, was exactly that of the apparatus. In practice the total loss could not well be reduced under 5 per cent., but it would be more uniformly distributed than by any

other method. He had quite recently been shown a copy of the reports by Mr. Douglass and the Messrs. Stevenson on the Trinity House and Scotch lanterns, from which it appeared that the Messrs. Stevenson, using the same method of calculation as himself, found the obstruction of light in the Trinity House lantern to be 6·8 per cent., as given in the Paper. They also stated that the horizontal part of their lantern framing stopped no light, as it was in the shadow of the corresponding framing of the apparatus. The cost of the Trinity House framing, 14 feet diameter, and 10 feet high, was—

	£.	s.	d.
3,778 lbs. of steel framing, at 1s. 9d.	330	11	6
1,267 „ gun-metal capping, at 2s. 6d. . . .	158	7	6
Cylindrical glazing, ½-inch thick.	362	6	3
Total cost	£851	5	3

The total cost of the improved lantern, at the same schedule of prices, with the same section of steel, was—

	£.	s.	d.
3,576 lbs. of steel framing, at 1s. 9d.	312	18	0
1,063 „ gun-metal capping, at 2s. 6d. . . .	132	17	6
Cylindrical glazing, ½-inch thick	233	13	0
Total cost	£679	8	6

Thus a saving of £171 16s. 9d. was effected in addition to the economy of light. It was not, however, necessary to adopt a diameter of 14 feet, or to use plate glass ½ inch thick. He preferred a diameter of 12 feet 6 inches for the inside of the glass, allowing an internal diameter of blocking of 12 feet, and he thought ⅜ inch was ample thickness for the plate glass. The Messrs. Stevenson and the French Engineers preferred a diameter of 12 feet, the former using glass ¼ inch thick in all their lanterns. Spare panes were supplied with every lantern, but in addition there should always be storm-panes, as they could be erected in case of necessity in a few minutes. Every attempt of the light-keeper to maintain a good flame, or even any flame, would be futile, if a single pane were broken so as to let in the wind. A lantern framing of the improved system, having an internal diameter within the glass of 12 feet 6 inches, and glass ⅜ inch thick, would cost about £425, or one half of what was now paid by the Trinity House. The extra cost of an increased diameter of glazing did not stop there, but extended to the cupola, blocking, and finally to the tower itself.

The reports on lanterns laid before the Board of Trade, and referred to by Mr. Douglass, related to two forms of lanterns only, that adopted by the Trinity House and the other by the Commissioners of Northern Lights; and no mention was made of the improved system of framing. He did not adhere to any par-

ticular inclination for the lens panels, but when that inclination was settled, the lantern should be constructed to correspond. The uniformity of the light from the apparatus used by Mr. Douglass would be improved by having the racks of the upper and the lower reflectors placed so as not to come vertically over each other. He strongly disapproved of vertical framing for the reflectors, while inclined framing was used in the lantern; and of inclined framing for the reflectors, when a different inclination was used in the lantern; as under such circumstances the framing of both the apparatus and the lantern stopped light. The Trinity House light at Gibraltar was marred by the vertical lantern bars not coinciding with the vertical framing of the apparatus, by which the obscuration of light was more than doubled.

As lanterns of a sufficient strength could be constructed on any of the known plans, it was unnecessary to discuss which form of framing was theoretically the most perfect, in regard to a maximum strength with a minimum weight of material; but it was important to construct a lantern of ample strength with a minimum loss of light, and at the least expense. He claimed for his lantern superiority in these three points. He considered a shallow capping $\frac{1}{8}$ inch thick more suited to prevent the accumulation of snow on the lantern framing than one upwards of 1 inch deep, as used by Mr. Douglass. During a snow-storm one of the light-keepers should be outside the lantern to sweep the snow off the capping and glass. He was of opinion that Mr. Douglass' lantern would carry a greater bulk of snow than any other. No doubt, when Professor Faraday reported in reference to Mr. Douglass' lantern that it was "nearly a matter of indifference as regards shadow how the uprights of the optical apparatus were placed in relation to such a lantern," he was aware that the whole of the framing would stop light, no matter where placed.

The composition of the glass varied considerably; and as a natural result the index of refraction, colour, hardness, and non-liability to change colour, all varied. The allowance of $\frac{1}{8}$ inch for grinding was necessary on account of the rough surface of the cast glass, the inaccuracy of shape resulting from the imperfection of the moulds, and the contraction in cooling and handling which sometimes took place before the glass was set.

The lantern which he had described was as good as any of the old lanterns for illuminating the sea from the horizon to the tower: it was also suited for any required dip, as that was accomplished in the apparatus, and no obstruction resulted from the lantern framing, unless it was incorrectly placed. The brightest light was generally sent to the horizon, but with a properly adjusted apparatus there would be a good light in-shore.

November 24, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,185.—"The Roman Rock Lighthouse. Simon's Bay, Cape of Good Hope." By JOHN FREDERICK BOURNE, M. Inst. C.E.

SIMON'S BAY, which is the north-western indentation of False Bay, contains the dockyard and depôt of the Cape Naval Station; and is the port chiefly sought by merchantmen of all nations coming in distress from the eastward, or damaged at sea immediately off the 'Cape of Storms.'

The Roman Rocks consist of a large mass of granite boulders, lying in the bight of Simon's Bay, about 2 miles from the shore, and immediately in the track of shipping entering or leaving the harbour, which is inside the point off which these rocks are situated. There are ship channels inside and outside the rocks. Until within the last seven or eight years, a lightship had been moored to leeward of them. But the lightship showing signs of decay, and occasionally getting adrift during heavy gales of wind, the Board of Trade, at the instance of the Admiralty, decided on erecting, instead of it, a lighthouse upon one of the rocks. A plan and contour of one of the rocks were sent home about eleven years ago; and the late Mr. Alexander Gordon (M. Inst. C.E.) was intrusted with the design, and with the superintendence of the construction of the iron-work and lantern in England.

The design was for a circular tower, 15 feet in diameter and 48 feet in height, of cast-iron plates, with a central column, 16 inches in diameter, in which the weight of the revolving machinery descends. The tower is surmounted by a lantern and gallery as usual. There are eight plates in the circumference of the tower, and six plates, each 8 feet long, in the height, the plates being $1\frac{1}{4}$ inch in thickness. But to admit of the horizontal joints of each vertical set of plates breaking joint with those of the contiguous vertical sets, there are four plates of 4 feet high each, and four of 8 feet each in the first and last horizontal sets of plates. The door cill and level of the first floor are 24 feet from the foundation; the whole interior up to that level being intended to be filled in with concrete. Below that level the flanges of the plates are outside; above it they are inside. If the building, as designed, had been skilfully and carefully erected, and filled in

with good material, there is no reason to doubt that it would have answered the required purpose, and have stood well. But it failed, and was condemned as being dangerous.

The object of this Paper is to point out the causes of failure, and to give an account of the mode of securing the tower against further injury.

Of the Roman Rocks the principal is about 80 feet in length at low water, by about 40 feet in width at the widest part, which is about one-fourth of the distance from the leeward, or shore end. The rock tapers irregularly from this spot to a sharp point at the windward or southern end, and it is somewhat rounded off towards the shore end. The extreme point, to windward, stands about 6 feet above the level of dead low water at spring tides; the centre of the rock is about 3 feet lower than the point, and the contour rises again, to about 5 feet above low water, at the highest spot near the rear. This rock, therefore, may be compared to the back of a horse, with the shoulder to windward. The best position for the lighthouse would certainly have been about 10 feet further to the rear than that actually selected, in fact, the highest available position; but, unfortunately, the hollow of the back was chosen, on account of its being more level. Spring tides rise about 5 feet; neap tides 1 foot or 2 feet, and sometimes scarcely at all. There is almost always a heavy surf breaking upon the rocks; and only on one day, in the course of three years (1865-7), was it so calm that no sea broke over at low water. On that occasion, for an hour or more, water had to be dipped up for the use of the drillers.

The highest position should have been selected, to prevent the workmen being impeded when cutting the foundation pits and fixing the first row of plates, but the lowest spot was chosen; and this was the first cause of trouble, and led to immense additional expenditure of time and money. For even at dead low water, and when it is considered quite calm, there is invariably sufficient swell to strike the point of the shoulder; and it was always found that the 'run' of the sea swept over the back—frequently a 'run' from each side, first from one side and then from the other: only one now and then, a 'master sea,' being of sufficient bulk and force to wash completely over the rear.

The lowest spot having been chosen, the next error was cutting the foundation pits too deep into the rock, for the purpose of getting as much solid core as possible for the inside of the tower. In order to obtain a core of 6 inches at the lowest spot it was necessary to leave it 2 feet 9 inches high at the highest point; and as the groove was formed by blasting, for the sake of saving labour and time, the rock was much injured. Every sea of course filled the annular foundation pit, rendering it difficult to work.

Two channels were therefore made, by blasting, one on each side, to allow the water to run off; and these channels were very annoying at a later period. It was found impossible to cut the foundation pit true and level, or so difficult that the attempt was abandoned; and the holding-down bolts were so imperfectly secured, that some of them drew when screwed up. Nor was the circle true in plan. Not only had the bottom flanges of the plates to rest upon uneven bearings, being wedged up in some places with blocks of teak, but they were forced, when screwed together, to take a form to which they were not cast.

It was necessary to wait for fine weather to set the first tier of plates and fill it in with concrete to the level of the half plates, or 4 feet from the bottom flange. It was feared, it is said, that the concrete would swell and burst the plates; and therefore a system of sheet-iron bulk-heads, not originally designed, was introduced; and wooden shores were also inserted and wedged up, which would, no doubt, have a worse tendency than the concrete, especially if the wedges were dry when driven. At all events, it so happened, that, when the plates were all tightly bolted together, and the concrete was filled in to its full height of 24 feet, the plates began to crack vertically in six different places, one crack extending 28 feet high; so that it became necessary to hoop the tower with wrought-iron hoops, of double $1\frac{1}{2}$ inch round iron, the hoops being about 6 inches apart.

In this condition the lighthouse was completed and was used for some time. The erection occupied five years, and the cost is stated to have been about £17,000. It had been previously estimated that one year would be sufficient for the erection; but the difficulties arising from the constant surf, the tides, and the weather were altogether unknown.

An arrangement had been made, between the Imperial and the Colonial Governments, that the lighthouse was to be built by the Imperial Government, and, when completed to the satisfaction of the Colonial Government, to be thereafter maintained and lighted by the colony. But, on inspection, the state of the plates was found to be very bad, and the wrought-iron hoops were already rapidly corroding; as, on account of the surf, it was not possible to give the lower ones any efficient protection. The structure was reported as altogether insecure; and the Colonial Government refused to take it over for maintenance in its patched up and unsafe state. It was, however, lighted by the colony. In 1862 and 1863 a long correspondence took place between the two Governments on the subject; and soon after the Author landed at the Cape in 1863 he was desired by Sir Philip Wodehouse, the Governor, to inspect the lighthouse and report to him. This led to a proposal being made by the

Author, which was eventually adopted by the Board of Trade, after it had been approved, in preference to others, by Sir Baldwin W. Walker, the Admiral in command of the station, that the tower, as it stood, should be surrounded to the level of the first floor, a height of 24 feet, by a concentric ring-wall of granite, 4 feet thick, with a backing between the wall and the iron plates of about 8 inches of cement concrete. The proposal was to have, in the first six courses, sixteen stones only in each course, fastened together with dowels; each stone to be accurately dressed, to be about 2 feet thick, 4 feet wide on the bed, and to be carefully laid in Portland cement, which the Author had successfully used for about eight years in marine works in British Guiana. The backing was designed to consist of the débris of the quarry, mixed with the same cement. The upper courses were to be of rather smaller stones, dressed only on the face and bed; to be of irregular width on the bed, as the quarry might allow; and to be backed by rubble masonry in cement up to the plates. The coping was to be of dressed stones extending to the flanges of the iron tower. Iron stanchions and a hand-rail were to form a gallery round the tower at the level of the first floor.

As it is seldom possible to land on the rock, even at low water, for the purpose of visiting the lighthouse, a light stage had been constructed, on a level with the floor of the house, and extending from the door towards the shore, over the rear of the rock, above which it was supported by two iron stanchions. Gallows posts, with block and tackle, and a 'Jacob's ladder,' to be let down when required, formed the means of communication with boats, which could only approach from the leeward, or shore side. There a mooring had been laid down, with a buoy and surf line to the iron stanchion of the stage.

The same system was adopted for the landing of the stones, &c.; but the whole had to be renewed with heavier material, as the stage was required to carry a traveller, with a stone weighing upwards of 3 tons, not hanging steadily, but jerking and swinging with the excessive motion of the barge. To carry the stones round the house to their proper sites, it was proposed to fix a circle of fished railway bars to the tower, on brackets projecting about 2 feet from the plates; and to use a traveller with only two double-flanged trucks, the hook to which the stone was to be suspended being bent round and below the rail, so that the point of suspension should be directly under the tread of the truck wheels. This was found to answer exceedingly well. The rail was below the level of the landing-stage, so that a stone might run completely round the tower, and it was afterwards built into the wall, and the upper stones were run round on iron rollers coned to the proper circle.

It was at first intended to carry out the stones in a large barge, to be manned from any ship of war which might be able to supply men. But it was afterwards found that the danger and risk of loss rendered it preferable to carry out only one or two stones at a time, with the men constantly employed upon, and therefore accustomed to landing on, the rock, to drill the foundation pits. A small punt was accordingly built, with a well in the centre sufficiently large to hold one of the largest stones, and with watertight compartments fore and aft, of such size as that, when laden with a stone, and the well filled by a sea, the punt would float 4 inches out of the water. This punt was towed out by the workmen, with the lifeboat constantly used by them.

A quarry was selected on the land forming the southern point of Simon's Bay, and consequently as far to the windward as it was possible conveniently to get. Some large granite boulders afforded shelter from the south-east winds, and a small bay to the leeward of the boulders was chosen as a convenient shipping-place. Rails were laid down, and a crane and sheers erected as required.

Authority to commence the work on these plans was given by the Governor in January, 1864, and the Author had charge as the superintending Engineer. From the 1st of February, 1864, a journal was kept by Mr. King, the resident Engineer, of the progress of the work, until its completion in 1867, from which copious extracts are given in the Paper.[1]

It appears that at the best of times there was no chance of doing anything on the rock until the tide had fallen about three hours; if from that time to the turn of the tide at low water it was found impossible to work, of course it was of no use to wait any longer. The foundation pit was cut by drilling holes $1\frac{1}{2}$ inch in diameter, in concentric and radial lines, to the required depth, and breaking the pieces out with plug and feather. One of the largest pieces got off in this way was about 4 feet by 1 foot, by from 8 inches to 9 inches, from a high piece of the rock. The bed was then dressed with cutting hammers and chisels, until it was perfectly true and level. It was found that the whole foundation could be got out in two levels, the lower level to carry nine stones, the upper level to carry seven stones. The difference in level was 8 inches; and the nine stones for the lower level were therefore dressed to 8 inches thicker than the others, and weighed about 3 tons 6 cwt. each. The holes of course varied in depth, from 10 inches to 12 inches, according to the contour of the rock; and each hole of $1\frac{1}{2}$ inch diameter was bored in an hour. The lower level was

[1] It has not been thought necessary to print these extracts *in extenso*, as the Original Communication may be consulted at the Institution.

not so deep as the old foundation pit, or as the channels previously referred to, which had been blasted out to allow the water to run off, and were to be subsequently filled up again. The abstract of the journal shows that in two hundred and sixty-nine days after the work was commenced, in 1864, there were one hundred and two days on which it was possible to do something on the rock, giving a total of 1,096 men, 356¾ hours; whilst in the same number of days in the year 1865 there were only forty-two days when the work could be proceeded with, giving a total of 550 men, 126½ hours. But the year 1865 was exceptionally bad.

The number of hands employed, all told, was generally nineteen. The four masons and two smiths received 6*s.* 6*d.* a-day each; and the labourers, who were engaged in drilling, quarrying, and rough-dressing, and in pulling out to and back from, and working on the rock, received 4*s.* 6*d.* a-day each. It was seldom possible to work on the rock without being drenched by every sea. One one occasion, Mr. King, the resident Engineer, was washed off the rock, not having time to lay hold of the life-lines or the chains of the tower; and on two or three other occasions the same accident happened to some of the men. The Author was more than once washed off his legs, but was holding on to the stanchions at the time. The life-boat was always kept with a boat-keeper at the mooring-buoy to leeward, and was fortunate in picking up all the men that were washed off; and it was satisfactory to be able to record, that the whole work was completed without any serious accident to the men. In making the estimates it was calculated that four of the ninety-six large stones might be lost, either in transport or by being washed off the rock; but only two were lost.

It is said that when the iron building was in course of erection, an attempt was made to fill in the gullies with asphalte; but the project was abandoned, as even in the most favourable weather the asphalte would not stick either to the rock or to the iron work. No difficulty was, however, experienced in filling the old pit and gullies in favourable weather with Portland cement, mixed with very little sea-water and chips of granite from the quarry. A plank was cut to the curve of the tower, and was shored down upon this rubble-work by shores from the tower-hoops and flanges. To divert the sea as much as possible from the work, strong iron stanchions were fixed on both sides of the rock, where the gullies had been blasted out, and in front of the stanchions planks, scribed down to the rock, were fixed by strong staples slipping over the stanchions, and then screwed up tight with nuts. But these weather-boards, though useful in fine weather, could not often be taken advantage of. A temporary protection for each short length of pit as it was about to be filled was made with gunny-bags, filled some with sand and some with clay, which, when the weather allowed the work to be carried

on at all, could be held in their places by a few men told off for the purpose. The low gullies or channels already alluded to were levelled up in the same way, with flakes of granite and Portland cement. But the rock was first cleaned and roughed with cutting-hammers; holes were drilled, and iron bolts, $1\frac{1}{2}$ inch in diameter, were inserted, and cut off accurately to the required level. On a favourable day the gunny-bags were prepared, and put into position to be ready instantly, and so as to act as a breakwater in the mean time, a guard of men being set over them. A small tarpaulin was laid down to windward of the gully, with some of the bags upon the windward edge of it, men holding by the stanchions, standing or sitting on the bags. As the stiff cement and flakes of granite were laid, they were covered with the tarpaulin and bags; and when all was finished and well covered down, the Author and all hands sat or stood upon the bags, until the rise of the tide and heavier seas rendered it no longer possible. The bags were then fastened down as well as could be effected, but they were soon washed away. It was some months before the weather would permit of a stone being laid on this foundation, which was then dressed to receive it, and was found perfectly good and sound, and almost as hard as the rock itself.

The first stone was taken off and safely landed on December 26, 1865. But it was some months before the first stone was laid, as a succession of gales occurred, during which two of the stones were lost. Having landed three stones, with no prospect of weather good enough to allow of their being set, it was determined to secure them as well as possible, and wait. They were placed in the deep part of the foundation-pit, abutting against the step of the high level, and were wedged up at the front and the back, and were shored down from the tower-hoops. Chains were passed through the lewis rings, and thence to the tower-hoops; and several chains were passed round the stones, and wedged up tight and as securely as possible. But with all this, the three broke adrift, of which number two were altogether lost, and the third still remained, held only by the lewis chains; and it swung about so constantly, and struck the iron plates with such force as to break off the flange and a portion of one of them, and produced such a vibration in the whole house as greatly to alarm the lighthouse-keepers, who signalled for assistance.

On the 20th March, 1866, the first stone was laid. The *modus operandi* may now be described. The weather-boards being fixed to the stanchions, a stone, which when landed had been chained to the tower on the lee side, was lifted by the compensation blocks, suspended from the hook of the traveller on the circular railway. The surfaces were then carefully cleaned from the vegetable and animal matter which in a few days began to adhere to them, and

well scoured with sand. The exact place of the stone was scribed on the rock by means of an iron template, an iron pin having been previously driven flush at each outer corner. Two or three men were told off to hold the bags of sand and a piece of tarpaulin, as a temporary protection to the bed of cement from the sea. The cement, timed so as to be ready, and with as little water as possible, was spread, and the stone was lowered into its place. A little oakum was stuffed into the joint, to keep the sea from washing out the cement, but it was not tightly caulked in. The large eye-bolt by which the stone had been suspended was unscrewed, leaving the nut in the countersink below; and thin cement was poured into the hole, and tamped down with an iron rod till the hole was quite filled. Two iron pins, 1½ inch in diameter, were then driven about 4 inches into the rock, standing up about 3 inches, at a distance of about 4 inches or 5 inches from the corner; one on the circular face, and the other in the next joint, to keep the stone quite steady in its proper position under the pressure of the concrete behind, and the blow of the sea. The next contiguous stone was axed out in the proper place, to let it pass over this latter plug. This next stone, if time allowed, was treated in the same manner at once, dogged to its neighbour, and, without loss of time, stiff cement and broken rubble were filled in between the stone and the house; and pieces of granite, previously cut to fit, were laid in cement in the groove remaining between the convex face of the stone and the side of the foundation pit, wherever it was deep enough to admit of it. Pieces of plank, cut to fit the iron plates, were shored up against each end of the concrete backing, and another piece, if the work had to be left, was shored down on the top—a quantity of dry cement being first powdered over the concrete, to form a crust as soon as possible. But, if time and tide allowed, a third stone was laid on the top of the other two, to weight them down, and form a good abutment for the next stones.

The work was commenced on the lee side of the tower, and carried round to windward on both sides for the first three courses, after which each course was commenced to windward; as, being 6 feet high, it was not so much exposed to the force of the sea, and it was more convenient in bringing round the stones.

The stones of the lower course were lettered A, those of the second course B, and so on; and the plan adopted, on Mr. King's suggestion, was to commence by laying 2 A's and 1 B, under the lee of the old tower; then, on the next suitable days, 1 A, 1 B, and 1 C; the three courses being carried on together as much as possible, until they were all completed, when it was no longer a matter of such difficulty to work in tolerably favourable weather.

Although bad weather was constantly recurring, so that it was not possible to take out any stones, yet the difficulty and anxiety

were now over. There was no further any doubt as to the possibility of the work being satisfactorily completed. What had been done had been thoroughly well tried. It was now a mere question of weather alone. If that were sufficiently good to allow of the barge being towed out with its load, and the load landed, it could be laid. The Author has sometimes seen the barge and its load completely buried by every sea as it rushed over the rock; the two men left on board to 'hook on,' and to keep the barge off the rocks from the undertow, having to hold fast for their lives. As the stones last required were smaller in size, and could be taken out, landed, and laid either at high or low water, provided the weather were favourable, it was now found practicable to obtain a boat's crew from any ship of war which might be lying in the bay on application to the commander through the commodore; and whilst the seamen were towing out the load, the masons and labourers were employed in laying the previous load. A lewis was used for lifting these stones instead of the large eye-bolt with countersunk nut.

By the end of 1866 the work was at a proper height for putting on the coping; but towards the close of the year the weather was chiefly 'north-west, very strong, with heavy squalls.' During the month of January, 1867, however, at intervals, stones for the coping were carried out and landed, and by the 27th of February following the work was completed, and was taken over by Mr. Elton on behalf of the Colonial Government.

This was truly termed, by the old navigators, the 'Cape of Storms;' and the satisfactory termination of the work was due entirely to the energy and perseverance of Mr. W. F. King, the resident Engineer.

It might be supposed, from the nature of the work, that the health of the men would frequently suffer. Such was the case when they were much exposed to rain. They complained chiefly of rheumatism. A provident and sick fund was established soon after the works began, and was of great service. The men paid sixpence a week each to this fund, and were allowed 14*s*. a week during the first six weeks of sickness, and 7*s*. a week during the second six weeks. Beyond twelve weeks, the question of further payment was to be decided by a majority of the workmen; and proper rules were agreed to as a check against malingering, &c. At the close of the works a balance of several pounds was divided amongst the subscribers to 'The Roman Rock's Lighthouse Works' Provident and Sick Fund.'

The communication is accompanied by one drawing.

[Mr. Bourne,

Mr. Bourne, in answer to questions, said that the stones forming the lower portion of the tower were cramped together with iron cramps. They were laid with Portland cement, and were backed up with Portland cement concrete between the ring wall and the old tower. When well made the cement soon became as hard and tenacious as the stone itself, entirely dispensing with the necessity of dovetailing, which could only be of temporary service. During the progress of the work, the Cape was visited by very heavy gales; and in the year 1865, the most violent storms ever known in that locality occurred, and he personally witnessed sixteen vessels go ashore in one day in Table Bay. Yet after a few of the stones had been laid, and while they were comparatively unprotected, the cement being nearly green, the stones, though exposed to heavy seas, remained perfectly secure.

Mr. Bourne added, that the Paper was intended chiefly for the use of the junior members of the profession, to whom he thought the details might prove useful.

December 1, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—Charles Graham Blatchley, George Broadrick, Thomas Forster Brown, Alexander Cato, John Henry Hartwright, John William James, Alfred Roberts, Robert Roberts, Robert Watson, and George Woodbridge, as Members; Samuel Parker Bidder, Junior, Richard Shaw Brundell, Frederick Charles Bullmore, Thomas Procter Campbell, Elliott Scarlett Currey, John Gomes Vieira Dantas, Francis Gordon Davis, Walter Mardon Ducat, Captain, R.E., John Stinson Farmer, Henry Augustus Fisher, Thomas Penn Gaskell, George Harrison, John Thomas Holgate, Edmund Lane, Henry Christopher Digges La Touche, Edward Antoine Sacré, John Nidd Smith, Edwyn Joseph Statham, Thomas Selby Tancred, Henry Andrew Vivian, and William Webster, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye Laws, as Students of the Institution:—Richard Harrison, Killingworth William Hedges, Francisco de Sallis Torres Homem, Joseph Prime Maxwell, William Henry Read, and Charles Robert Western.

No. 1,147.—"Description of the River Witham and its Estuary, and of the various Works carried out in connection therewith, for the Drainage of the Fens, and the improvement of the Navigation."[1] By William Henry Wheeler, M. Inst. C.E.

The Institution of Civil Engineers having offered a premium for a Paper on the History of any Fresh-water Channel, Tidal River, or Estuary, it is considered that the history of the Witham will fully meet the requirements of the Institution, the science and skill of the engineer having made use of this river in extensive works of drainage, by means of which several thousand acres of land, formerly nothing better than a swamp and a morass, have been converted into one of the richest and best cultivated districts in England. Its history will include a description of the works which have been executed on the river and its estuary, and in making the drains in connection with it.

[1] The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

The communication will be divided into three parts :—

1st. A general description of the Witham; its ancient history, and the various works in connection therewith, from the time of the Romans to the present day.

2nd. The effect of the works on the tidal portion of the stream, —particularly of the effect of sluices across tidal rivers, and of enclosures from the sea, and of groynes and parallel training walls; —and an account of the works that have been carried out for its improvement.

3rd. The present state of the estuary, owing to the gradual encroachment of the sands on the sea, materially affecting the drainage of the district and the navigation of the port; and the means which are recommended for its improvement.

The Witham derives its source near South Witham, a village about 10 miles north of Stamford; thence it flows almost due north to Lincoln, and nearly up to this point is simply a small stream left in its natural state, and draining the lands through which it flows. From Lincoln it takes a south-easterly direction through a level tract of country to the sea, and passes on its way the town of Boston, called, from its situation, the metropolis of the Fens. (Plate 8.)

Formerly the tide used to flow up the Witham without restriction, and at one time it is believed it even reached as far as Lincoln, thus enabling ships of considerable size to navigate the river. It is this portion, from Lincoln to the outfall, flowing through a low fenny tract of land, and on which the skill of the Engineer has been employed to make it subservient to the purpose of drainage, that will form the subject of the Paper.

In addition to the upland waters that the river receives from its source to Lincoln, embracing a large area of land, it also takes the whole of the waters of the northern portion of the Lincolnshire Fens, known as the 1st, 2nd, 3rd, and 5th districts; likewise the East, West, and Wildmore Fens (the 4th district), and Holland Fen, comprising about one hundred and thirty-seven thousand acres of land. This vast level has, according to geologists, undergone several changes, which it may be interesting, even in an engineering point of view, briefly to consider.

It is supposed that the general surface of the fens in the neighbourhoods of Boston, Spalding, Wisbeach, Lynn, and the other fen towns, was, near the outfall of the rivers, from 10 feet to 18 feet lower than it now is, and that the upper part of the great level of the Fens was anciently 5 feet lower than at present. The lower part was covered daily by the tide, and the land was in a condition similar to the salt marshes to be found at the present day on these coasts. The lands in the upper part of the level, although 5 feet

lower than now, and below high-water mark, were never hurtfully annoyed by the tides, but were in the condition of upland meadows, and the soil sufficiently sound and good to grow trees of considerable size.

It was while it was in this condition that the Romans came to England; they, for military purposes, cut down the trees in the upper part of the level, and constructed banks for keeping out the tidal waters. The construction of these banks had a tendency to silt up the rivers that carried off the upland waters, and their beds were gradually raised. After the departure of the Romans, the banks and sluices were neglected, the tide again flowed over the Fens, through numerous breaches, depositing the silt and mud that it washed up and carried with it. The water coming down from the high lands bordering on the Fens, washed away the soil it passed over, and finding its egress to the sea obstructed by the choking up of the rivers and the embankments, remained stagnant for some time and deposited the sediment it contained. This state of things existed for a great number of years, and the surface of the Fens became gradually raised till it attained its present level. After the arrival of the Normans the banks were again attended to, the sluices repaired, and the higher parts of the level brought into cultivation; but the lower lands remained, until within about a century ago, in a state which is described as being little better than a vast morass.

That the land was originally several feet lower than at present is inferred from the facts quoted by Dugdale in his history of embanking and draining, where he states that in the year 1635, when deepening the Wisbeach River, the workmen, at 8 feet below the then bottom, came to another bottom which was stoney, and in it were found seven boats which had there lain overwhelmed with silt for ages. At Whittlesea, in digging a moat, at 8 feet deep, they came to a perfect soil, and swarths of grass lying thereon, as they were at first mown. In digging the foundations for Maud Foster Sluice at Boston, there were found, at 16 feet below the surface, covered with silt, a smith's forge and all the tools belonging to it. In driving the piles for the Grand Sluice at Boston, in the year 1764, the workmen discovered the roots of trees standing in the same position as they must have done when growing, 18 feet below the surface. In digging for works in the year 1696, on the Welland, near Spalding, there were found, about 10 feet deep, the remains of old tan vats, a great quantity of horns and shoe soles, also a number of boats.

Numerous other discoveries of a like kind might be quoted, but these are sufficient to prove, that at one time the surface of the land near the estuary was considerably lower than at present, the level varying from 16 feet to 18 feet at the mouth of the river, to 5 feet

at a distance of 20 miles from the sea; that, while it was at this lower level, the land was inhabited and cultivated; that subsequently it was covered by the sea, and remained so for a number of years, during which time, by the natural action of the tides and the upland waters, the soil was gradually raised to its present level.

That the stupendous embankments by which this vast tract of country is protected from the sea, and on which its present safety depends, were the work of the Romans is evidenced by the fact, that as the general level of the country was so much lower than at present, every ordinary spring tide must have daily flowed over it; and neither the towns of Boston, Spalding, nor Wisbeach could have been built until the banks were erected. Dugdale asserts that these towns were inhabited by the Saxons; and as the tan vats, shoes, and implements that were found (as previously mentioned) were of the same form and shape as those used by the Saxons, it follows therefore that these countries must have been embanked before their time by the Romans.

These banks are many miles in length, and are works of immense magnitude. Previous to the coming of the Romans there was no organization in England capable of carrying out such an undertaking. The vast military system of the Romans, their talent for engineering, and the experience of many similar works, would enable them to throw up these embankments without difficulty. Other works testify to their having expended considerable labour in improving the Fens. The Cardyke, a large canal or drain, extending from the River Welland on the southern side of the county, to the Witham, near Lincoln, is generally supposed to have been made by the Romans for the purpose of intercepting the upland waters and preventing them from flooding the low lands (Plate 8). Its channel for nearly the whole of its course of about 40 miles is 60 feet wide, and it has a broad flat bank on each side, as may be distinctly seen at the present time.

It is then to the ingenuity and industry of the Romans that the safety of the whole level of the Fens depends; and by way of illustrating the importance of their work, it may be quoted, that an extraordinarily high tide, accompanied by a strong wind, which occurred in the year 1810, broke the sea-banks in several places. An immense quantity of water spread itself over the adjacent country, extending from Wainfleet to Spalding; great numbers of sheep and cattle were drowned; corn and haystacks were swept away; the town of Boston was deluged, the water rising as high as the pulpit of the church, and doing great injury to the houses and property of the inhabitants. The loss occasioned by this breach in the sea-banks, from the destruction of property and injury to the banks, was estimated at over twenty-eight thousand pounds. Other

breaches have occurred at different times, always doing great injury to the land, and causing great loss.

It has been stated that until about a century ago, notwithstanding all that had been done, the lower lands were still little better than a swamp.

The works undertaken for their recovery will now be described. The Lincolnshire Fens, which drain by the Witham, extend from the coast inland in a westerly direction until they gradually merge into the high lands, and are known by the names of the several districts into which they are divided for the purposes of taxation. The district nearest the coast is the East Fen, next to it are the West and Wildmore Fens, then the several districts adjacent to the Witham, extending northwards as far as Lincoln, and lastly the Holland Fen, comprising together the following acreage :—

	Acres.
Witham District.	
Fen lands draining by the Grand Sluice (1st, 2nd, and 5th districts)	33,897
Ditto, by Maud Foster Sluice, West and Wildmore Fens (4th district)	27,743
Ditto, by Hobhole Sluice, East Fen and 5,000 acres (4th district)	34,483
Black Sluice District.	
Fen lands draining by the Black Sluice . . .	46,215
Ditto ditto ,, Holland Fen, and 2nd and 6th Witham districts	30,646
	172,984

It would be out of place here to give a history of the various schemes and attempts made at different times for the enclosure of the Fens. These remarks will therefore be confined to the works actually carried out.

"By an inquiry made in the reign of Elizabeth (1599) concerning the draining of these Fens, it appears that the East Fen was found to contain five thousand acres or thereabouts, and that one half thereof, being the skirt, hills, and outrings, might conveniently be drained; but the other half, consisting of deeps, for the most part, could not be recovered." A Commission of Sewers, held at Boston in 1630, reported that great quantities of the land lying between the said East Fen and the Witham, were all under water in the winter time, and several works were ordered, to mitigate as far as possible this evil. A writer, in speaking of the enclosure of the Holland Fen in 1767, remarks: "The present appearance of Holland Fen, when contrasted with what it exhibited a century back, is a striking proof of the ingenuity and industry of man, and almost induces incredulity with respect to what they have in this instance accomplished. . . . The whole of the land between

Brothertoft and Boston was frequently overflowed during the winter season. The turnpike road from Boston to Swineshead, and the intersecting roads leading to the adjacent villages were covered with a considerable depth of water. Of course they were dangerous to travel upon; and the Boston people brought their produce to Boston market in boats, being enabled very frequently to come in them as far as Rose Garth Corner, in West Street."

This Fen, known as the Hautre Huntre or Holland Fen, was drained and enclosed in the year 1767. Many attempts had been made previous to this time by private adventurers, who in the reign of Charles I., in consideration of grants of a portion of the enclosed land, undertook to carry out the works necessary for draining and enclosing the whole level; and the Dutch Engineer, Sir Cornelius Vermuyden, was called in to assist the adventurers. About 1638 a sluice was built a little below the town of Boston, called the 'Great Sluice,' now the 'Black Sluice,' and a new drain about 8 miles in length, reaching to Swineshead, was cut to bring the waters of the Fen to this outfall, and the works of enclosing and draining were vigorously carried on. But the adventurers appear to have met with great opposition from the inhabitants, who pulled down all the new houses and buildings on the improved ground, destroyed the crops, and demolished the public works for draining the level; and to such a state had matters come, that in 1653 the adventurers had to petition the Mayor of Boston to punish certain persons for "pulling that great Sluice to pieces at Boston towne's end, which cost about six thousand pounds;" and they further remark, "if it should by this breaking-up be sunke by the water getting under it, the Sea will break in all that side of the country . . . and a hundred thousand pound damage done." Later they had to petition Parliament for protection and redress; but owing to the unsettled state of public affairs, and other causes growing out of the circumstances of the period they could obtain none. All the works that they had constructed at such cost were either pulled down or allowed to fall into decay, and the land again became, as Macaulay describes it, "a vast and desolate fen—a dreary region covered by vast flights of wild-fowl, and inhabited by a half-savage population, who led an amphibious life, sometimes wading, and sometimes rowing from one islet to another; and the roads through which were the worst in the world."

In 1767 a last successful attempt was made. The whole of the waters were brought to the original outfall at the Black Sluice, by a drain running through the centre of the Fen (Plate 8), its length being upwards of 20 miles, and its depth and width being sufficient to allow of the passage of boats, the drain serving also a canal for conveying all kinds of produce from the

interior of the Fen to the town of Boston and the sea, and carrying back coals and other commodities. A sluice was erected at Boston for the exclusion of the tidal waters, and a lock made for the purposes of navigation. The total quantity of land drained by this canal, and subject to taxation, was 64,395 acres; and, in addition, about 30,000 acres of land drained by the Glen and other sources found their way to sea by means of the 'South Forty Foot,' as the drain was called. The outlet for the Glen waters, originally being by the Welland, was diverted to this new course, with a view to improve the haven, by the passage of as much water as possible through it. In the year 1846 the drainage being defective, partially owing to the subsidence of the land occasioned by the withdrawal of the water from it, an Act of Parliament was obtained, under the powers of which the 'South Forty Foot' drain was lowered from 4 feet to 5 feet on an average throughout its whole length. A new outfall sluice was made, having three openings of 20 feet each, one being constructed for a navigation lock; and the cill of the new sluice was made 6 feet below the old one. The drain has a regular fall of 3 inches per mile.

The whole of this Fen is now in the highest state of cultivation, and the value of the land, which before the drainage and enclosure was worth hardly five shillings an acre, has been increased more than six times.

The districts between the Holland Fen and the Witham were provided with a drain about the year 1720, called the 'North Forty Foot,' which, running nearly parallel with the Witham, brought the waters of that part of the Fens to the same outfall as the 'South Forty Foot' drain at the Black Sluice (Plate 8).

The Witham, as has already been stated, was originally a tidal river, and navigable as far as Lincoln—a distance of 30 miles. This fact is proved from boats, anchors, and other like things being found buried in the silt, at a considerable depth below the bed of the river in its present state, the whole surface of the land having been raised from causes to which reference has already been made. In the reign of Edward III., by neglect of the works of drainage, the river had become much silted up, and was "so obstructed by mud that ships laden with wool, wine, and other merchandize, could not pass as they used to do;" and on petition to the King, the river was ordered to be cleansed and widened. In the year 1500, by an Order in Council, Commissioners were appointed to consider and carry out the best means for improving the condition and drainage of the lands lying adjacent to the Witham and the navigation of the river. The services of a Dutch engineer, May Hake, were engaged, and it was determined that a sluice should be erected at Boston; and Hake was authorized to bring masons and others skilled in such work from Flanders, whence also was

obtained "all other stuff and materials necessary for the accomplishment of the work." Under Hake's directions the sluice was erected, but it did not effect the good that was expected, and there were constant and great complaints of the state of the drainage. Many other attempts were made to improve the river. In 1751 it was stated that Boston Haven "was worse than it was ever known to be, and that whereas formerly ships of two hundred and fifty tons could get to the town, then a small sloop of fifty or sixty tons could do so only on spring-tides." The decay of the haven was attributed to the diversion of waters from the Witham to other sources, by the construction of the 'North Forty Foot' drain, which took waters that originally found their way into the Witham, and discharged them at the Black Sluice, situated below the town; and by the diversion of the West Fen waters to their new outfall at Maud Foster Sluice, placed still lower down the haven (Plate 8). In 1762 a commission was appointed and an Act of Parliament obtained for the purpose of improving the river and the drainage. A new cut was made, and a sluice erected a short distance above the town (called the Grand Sluice), consisting of four arches, each about 21 feet wide, three being appropriated to drainage, and the fourth being used as a navigation lock; self-acting sea doors were hung on the outer side of the sluice, and in the interior were slackers, or draw-doors, for regulating the height of the water in the river. At the same time a new cut or canal was made, for some distance up the river, taking a more direct course than the old channel, and the rest of the river up to Lincoln was widened and deepened. The cost of these improvements amounted to upwards of sixty thousand pounds. It was then found in practice, and has been so ever since, that the drainage and the navigation interests were hostile to each other; and partly to remedy this defect, an Act was obtained in 1812 to enable the Commissioners to construct a new cut from Horsley Deeps (Bardney) to Washinborough, with lock-gates for the purposes of the navigation, leaving the drainage water to find its way by the old course. This partly remedied the evil, but still the drainage was found to be seriously interfered with by the navigation. In 1864, on the recommendation of Mr. Hawkshaw (Past President Inst. C.E.), an Act was obtained, giving power to raise money and carry out certain works of improvement. At present it is necessary for the passage of boats along the upper part of the Witham that a depth of 9 feet of water should always be kept at the cill of the Grand Sluice. Mr. Hawkshaw advised that the river from the Grand Sluice to Bardney Lock (23 miles) should be lowered to a uniform level of 1 foot below the cill of the Grand Sluice, equivalent to 5 feet below the existing cill of the Bardney Lock, and that the river should be widened so as to give a width of 50 feet at the

bottom for about one-half the distance, and diminishing to 36 feet at Bardney. This will involve the lowering of the cills and chambers of four locks, and the consequent deepening of the canals in connection therewith. The estimated cost is thirty-five thousand pounds, and Mr. Hawkshaw calculates that by lowering the bed of the upper part of the Witham the height of the water on the cill of the Grand Sluice can be reduced from 9 feet to 4 feet, and yet leave sufficient water for the navigation. It will also greatly improve the drainage of the district. The silt and other deposits in the haven will be kept lower, and the capacity of the river as a reservoir to receive the waters from the upper districts in times of flood considerably increased; the level of these floods will be lowered about 2 feet; the maximum level of the highest flood at present being 14½ feet above the cill of the Grand Sluice at Boston, and of high floods 13 feet. Many of the drains which at present have to use engine-power (as much as an aggregate of three hundred and fifty horse-power being used for this purpose) will then be able to drain by gravitation, saving great expense in coals and attendance.

The eastern and remaining portion of the Fens termed the East, West, and Wildmore Fens, are the lowest in level of any in the district (Plate 8).

An attempt was made to enclose and drain these Fens by Sir Anthony Thomas and others, about the year 1630, and a sum of thirty thousand pounds was expended in draining and enclosing the level. A court of sewers held in Boston, declared that the undertaking had been accomplished, and "they adjudged the same to be so drained, as that they were fit for arable, meadow, or pasture." Yet, after these works were finished, out of the forty-five thousand acres, at which these Fens were then computed, three thousand acres were left still drowned, and deemed irrecoverable. In 1801, an Act was obtained for the drainage and enclosure of these Fens. Previous to this time the westerly portions of the level discharged their waters into the Witham, at a point about 2 miles above Boston, at a sluice called Anton's Gowt, and the remainder was drained through Maud Foster's Gowt, a sluice discharging its waters into the haven, about a mile below the town. The three Fens together contain about forty thousand acres of land. Mr. Rennie was consulted as to the best mode of reclaiming and draining this large tract of land, and he advised that the upland should be separated from the lowland waters, and for this purpose that a catchwater drain should be dug, skirting the whole district at the extremity of the Fens, and catching the water as it fell from the higher lands adjacent thereto. The theory of this system is obvious: the waters flowing from the higher levels found their

way quickly off the lands, and filled the drains, damming back the water in the ditches, on the low lands, where it had to remain until the upland waters had found their way out to sea. These catchwater drains were made to empty into the old Maud Foster Drain, at a point about two miles and a half above its outfall, and sluice-doors were erected to prevent the upland waters backing into the fen drain. Maud Foster Drain was widened and extended, and a complete system of internal drains carried out in connection with it, and the whole of the waters of the West and Wildmore Fens, the greater part of which had, as mentioned above, found their way into the Witham by Sir Anthony Thomas's sluice at Anton's Gowt brought into it. A new sluice, with self-acting sea doors, was erected in the place of the old one.

The East Fen was drained by means of a new cut about 14 miles in length, and a sluice for the discharge of the waters into the haven built at Hobhole, about 4 miles below Boston. Great opposition at the time was offered to this scheme, it being contended that the diversion of waters from their ancient outfall into the Witham would take away from the scouring powers of the river, and that the haven would silt up, to the detriment of the drainage by the Witham and the Black Sluice, and to the injury of the navigation; however true this may have proved, as regards the effect on the haven, it is doubtful if any other scheme would have been so successful, and the present highly improved and perfect state of cultivation of the district is a proof of its success.

Owing to the cultivation of the land caused by this thorough system of drainage, and other causes, further works are now required to make Hobhole Drain as effectual as it formerly was, water lying in wet seasons for a considerable time on the lowest lands. This arises partly from the state of the haven, which will be referred to more fully hereafter, as affecting this in common with all the other drains—Hobhole receiving the greatest injury as being the outfall for the waters from the lands lying at the lowest level,—but principally from the fact that the land in the East Fen has settled, in some instances, as much as 2 feet 6 inches below its former level. The upper surface of the soil is full of peat and organic matter, and was saturated with water; as the soil in the course of years has been worked and cultivated, this organic matter has gradually decayed, and by drainage the soil has become less spongy, and more compressed, and has subsided from its original level, as much as from 1 foot to 2 feet. This is proved by buildings which were first erected on foundations laid on piles, which are now exposed, and by the diminished depth at which clay is found. The remedy proposed by Mr. Hawkshaw, who has been consulted, is first by a scheme for the general improvement of the haven, and the consequent lowering of the present low-water mark, a measure

requiring the co-operation of all the trusts interested; or, secondly, the erection of a sluice about the middle of the drain, and a steam pumping-engine to lift the waters from the low level portion of the drain into the higher.[1]

As a summary, it may be stated that the area drained by the River Witham comprises—the Black Sluice district by the 'South Forty Foot' or Black Sluice drain, including the high lands, discharging the waters from 134,351 acres; the Fen districts adjacent to the Witham and the upper watershed of that river, discharging at the Grand Sluice 448,885 acres; the West and Wildmore Fens, and the catchwater drain in connection with them, discharging at Maud Foster Sluice 49,073 acres; the East Fen and adjacent lands, discharging at Hobhole Sluice 34,483 acres; lands under the jurisdiction of the Court of Sewers discharging at various small sluices 13,600 acres; making together a total of 680,392 acres.

II.

Having now described the various works that have been executed for the drainage of the Fens, and the bringing of their waters into the haven, the next point for consideration will be the state of the haven, and the estuary into which these waters are discharged.

First, then, the present state and condition of the haven, as affecting the drainage and the navigation, and the causes which have conduced to its decay will be considered; and, secondly, the various means which have been proposed and adopted for its improvement.

The haven may be said to commence at the Grand Sluice, a short distance above the town of Boston, and after a devious course of more than 7 miles, joins with the Welland (which drains 35,500 acres of fen land), and merges into that large basin or estuary, formed by the outpouring of the waters of the Witham, the Welland, the Nene, and the Ouze, and called the Wash (Plate 9). The haven varies in width from about 100 feet at the town, to about 250 feet near Hobhole. The spring-tides rise to a height of 16 feet on the cill of the Grand Sluice, and coming up the river with an æger, last about two hours. The estuary into which the waters are discharged is about 300 square miles in extent. It is shallow and full of shifting sands, which are gradually but surely extending and gaining on the sea. The great quantities of mud

[1] Since the above was written two centrifugal pumps, driven by two 90-horse power engines, capable of lifting 700 tons of water per minute to a height of 5 feet, have been erected at Lade Bank by Messrs. Easton, Amos, and Anderson, under the direction of Mr. Hawkshaw; and a dam and lock-gates being placed across Hobhole drain, the water can now be lifted out of the upper part of the drain so as at all times to keep it at a proper level below the surface of the lower lands in the East Fen.—W. H. W.

held in suspension by the waters discharged from the rivers in time of flood mixes with the silt washed up by the tides; the two opposing currents meeting, stagnation takes place, and a deposit is left, which the back waters are not strong enough entirely to remove. This silting up of the estuary may be further traced to the following causes:—

A. The embanking and enclosing of the lands.

B. The erection of sluices preventing the free flow of the water.

C. The improved drainage, the erection of steam pumps, and the under-draining of the lands with tiles.

A. It will readily be conceived how the draining and embanking of the land would cause the silting up of the estuary. The waters formerly brought up by the tides spread themselves over many thousands of acres of land, forming immense reservoirs, which on the efflux of the tides poured their contents into the channels, with a force and continuousness sufficient to drive back the silt brought up with the tide, and to carry away the sediment sent down by the upland stream. The great impediment to the exit of the waters is the accumulation of this silt. In summer, when little or no water is discharged from the several sluices, the tides having a free course over many hundreds of acres of moveable silt, roll them about in one direction or the other, as influenced by the winds, and other causes; the channel sometimes varying as much as 80 feet to 100 feet in one tide. In winter, when vast quantities of water are discharged from the sluices, the fresh water overcomes the tidal, and having a different direction given to it, from the curves and angles in the banks of the haven, cuts out for itself a fresh course, rolling the silt away into what had, during the summer months, been the channel; but while it is doing so, it is hindered in its flow, and consequently holds back the waters waiting to come down.

B. The erection of sluices across the river has been another great cause for its decay, by the deposit of silt. An old writer on this subject has remarked, "In all rivers communicating with the sea, where sluices are erected, they prevent the union of the tides and freshes, stop their motions, and separate their operations and forces; they must reasonably be supposed to be, as experience demonstrates them to be, very pernicious and hurtful to the channels and outfalls of such rivers; as all dams and obstructions and everything which impedes the current and motion of the water must be." The object in constructing such a sluice is,—1st. To prevent the tidal water from finding its way up the river, and overflowing the banks and flooding the adjacent land. 2nd. For purposes of navigation. 3rd. To prevent the deposit of the silt brought up by the tide in the channel of the drain. 4th. As a

reservoir for the storage of the fresh water in summer, to prevent its gradual escape, and to confine it until a sufficient head of water has accumulated to scour the outlet.

The first object is easily met by strengthening the banks, and making them sufficient to withstand the tidal waters. As to the second, drainage and navigation interests are always inimical, and it is difficult, if not impossible, to combine the two effectually; but by deepening the channel it is quite possible to make it so that vessels may pass up with the tide, and return with the ebb. In the case of the Witham, there is no doubt that formerly before any sluice was erected, vessels of considerable size navigated the river as far as Lincoln. Where the tidal streams cannot be made available, it is far better that separate cuts should be made for navigation purposes alone.

The third and fourth objects will require fuller consideration. It is an error to suppose that by the erection of a sluice across a tidal stream, the deposit of silt and mud is prevented; on the contrary, it assists such deposit, and the stagnation caused by the sluice makes the water leave the suspended matter in the channel below the doors, and so stops all egress of the waters through the sluice. This has been the case at the Grand Sluice, and the other sluices erected in the Witham at Boston. During the summer months, the mud accumulates against the doors to a considerable extent, even as much as 3 feet higher than the water on the inside of the doors; and during the last three dry seasons there has been a deposit of 10 feet in depth of silt and mud against the doors of the sluice, preventing any water passing through them for several months, causing great expense in its removal when the rainy weather came. The bed of the river has been raised in proportion, thereby interfering with the navigation. (Plate 9, Section.) Vessels which at ordinary times would find their way to the several quays and wharfs are obliged to remain below in the estuary, and the shippers are put to considerable expense in employing barges to transport the cargoes to and from the town. The same result has ensued on other rivers where sluices have been erected. Early experience has had little effect in warning engineers from erecting these sluices. More than two hundred years ago, when the Denver Sluice was erected in the Ouze, it was found "that the tide waters being shut out of their ancient receptacles, and a great part of them being entirely stopped, they, for want of their proper motion, deposited so much of the silt with which they came loaded, as to choke up the river." It has been argued that by the removal of the sluice, the sand which is now left on the exterior of the doors would be carried up the river, and be deposited along its whole channel; but it should be borne in mind that it is not the silt or other matter held in suspension which is carried up or down the

river which chokes its channel, but that which is dropped or deposited in it by the obstruction of the current, the abatement of its velocity, and the diminution of its force. It is true there must always be between the influx of the tides and the descent of the freshes, a point of stagnation in some part of the channel, and there during such stagnation the mud will be deposited; yet when the tides have free course, this period will be very short, and the freshes following the ebb of the tide will carry such deposit down with them. Whereas, when the stagnation is caused by a sluice, the period is of long duration, allowing a much greater quantity of deposit which gradually accumulates; this would not be the case if the tide had free course, the weight and force of the returning ebb and the freshes being sufficient to remove it. One idea of the builders of this sluice was, that by holding the fresh water in the river above the doors, and allowing it to accumulate till it had attained a head, that the force of the water would be more efficacious in removing the accumulated silt, than if allowed to flow out by small quantities day by day; but in practice it has not proved so, for in dry seasons the silt has accumulated so rapidly as entirely to shut the doors and prevent the egress of any water at all. The operation of an artificial reservoir, held up for the purposes of scouring a channel, is very limited and irregular in its effect. The waters when set at liberty raise the silt, mud, or other deposit from the part where the waters immediately issue, scouring large holes, or making the channels at that particular part deeper than required, and only carrying it to some other place lower down the stream, where, the force of the water being spent, the mud is again deposited; and instead of mending and deepening only, makes the channel worse than it was. The erection of this sluice, then, appears to have been a great mistake; it was condemned by engineers at the time. Mr. Elstobb, an Engineer largely connected with the drainage of the Fens, says,[1] in a work published by him in 1793:—"And as to that great sluice lately erected at Boston, at the mouth of a fine, and what might otherwise be a very beneficial new river, a little above the town, for keeping out the tides; I am so far from expecting any advantage from the said sluice, that I am fully of opinion if it is kept constantly in use, and under the same regulations for damming up the water above as at the first, that in the course of a few years the channel, instead of being improved, will be greatly injured, and the outfall prejudiced thereby. And had that expense been saved, and the tides had free admission into the said new river, there is great reason to believe, that the channel and outfall would have in a short time been improved by the

[1] "An Historical Account of the Great Level of the Fens, called Bedford Level, &c." By W. Elstobb, 8vo. Lynn, 1793. Page 230.

weight and force of the returning ebbs, and the freshes descending with the rapidity, which the continuance of the indraught of the said river, after the turn of the tide at the outfall would occasion." Modern engineers confirm this view of the subject, and Mr. Hawkshaw, who was called in both by the Drainage and the Harbour Commissioners to report on the state of the river in the year 1861, and again in 1864, recommended, with other works, the removal of this sluice.

C. Another cause that has materially tended to assist in the silting up of the basin into which the waters of the Fens are discharged, is the improved drainage of the land by means of tiles, and also from the use of steam-power effecting the more rapid discharge of the waters. The rain which fell on the land before the adoption of a system of under-draining took some time to percolate through the soil, and find its way to the ditches, and thence into the drains; the process was very gradual, and a small though constant supply was kept up to the large drains. These, in turn, poured their waters into the estuary in such a gradual manner, that before one fall of rain had cleared itself from the lands another succeeded; and so a constantly running stream was maintained, which, being daily at work, was sufficient to carry back with it the deposit brought up by the tide. But by the adoption of drainage by tiles the water quickly percolates through the surface soil to the drain-pipes, and by them is rapidly conveyed to the ditches; and these being kept clean and free from weeds, as rapidly discharge it into the main drains. The flow in these is assisted by the waters thrown into them from the low lands by the steam-engines, which are kept constantly at work pumping; and so the waters, receiving additional power and impetus by accumulation, discharge themselves very quickly. A short, but for the time, rapid fresh takes place, which drives before it the sand and mud that impede its course in the river; but before it has had time to move this deposit any distance its power is exhausted, and the material is only moved a little lower down the channel. Straightening the bends of the upper part of the Witham which receives the upland waters, also assists the waters in discharging themselves more rapidly by shortening their course.

That the winter rains are cleared from the lands very soon after their fall, instead of forming so many springs for the supply of water to the drains during the summer months, as formerly, is proved by the fact that although the Witham is the means of drainage of an immense tract of both upland and fen, in dry seasons, during the summer months, no water flows through it to the sea; and during the last three dry summers the doors of the Grand Sluice for several months were entirely closed.

Briefly to recapitulate the above remarks, it may be observed, —That all rivers carry with them in their flow large quantities

of soil, partly brought down from the hills, and partly washed up from the land over which they run; that wherever the flow is stopped, and stagnation occurs, the soil, being heavier than the water, is deposited on the bottom of the river or estuary; that the tides, meeting the freshes, cause a point of stagnation, deposit takes place, and where the back-water is not sufficient to wash this away, an accumulation of mud and sand occurs, choking up the outlet and raising the bed of the river. Before Art was brought to bear on the Fens in their natural state, the waters, flowing all over the low lands, formed huge reservoirs, which on the return of the tide made the freshes sufficiently powerful to carry out to sea the sand and mud deposited, and to keep the rivers scoured out to their proper depth: that by embanking these lands, and confining the waters to their channel, the tides become stronger than the freshes, and the sand and mud are deposited at the mouths of the rivers, to the detriment of their discharge; that, further, by the improved drainage causing the rapid discharge of the waters, the freshes are sudden and impetuous, instead of constant and gradual, allowing the deposit brought down by them to be washed back by the tides and to be deposited in the beds of rivers; and that this takes place to so great an extent as materially to raise the level at the outlet and interfere with the drainage, and that the more the operations of Nature are interfered with the greater is this effect; that wherever sluices or weirs are erected across a tidal river, by causing a longer period of stagnation at the point where the sluice is erected, and preventing the scour of the returning ebbs, a large deposit takes place, requiring the whole strength of the winter floods to effect its removal.

III.

There now only remains to be considered the present state of the estuary as affecting the drainage and navigation, and the works that have been proposed and carried out for its improvement. This estuary is a large bay, known by the name of the Wash, and receives the waters of the Witham, the Welland, the Nene, and the Ouze,—the great fen rivers of Lincolnshire and Cambridgeshire. (Plate 9.) The area of this bay is about 300 square miles, and about two-thirds of it consist of large beds of shifting sands, laid dry at low water; the depth of the estuary varies from 1½ fathom to 18 fathoms. The channel for vessels coming to Boston up the Witham is both tortuous and difficult, owing to the numerous shoals and shifting beds of sand. The course is marked out by buoys laid down and maintained by the Harbour Commissioners of the Port of Boston. The foreshore of the coast at the point where the Witham debouches is a hard, stiff clay, known by

the name of "the Scalp;" along this the water flows in a south-easterly direction for some distance, and then turns suddenly in a north-easterly direction, the Scalp forming a long elbow round which the waters have to find their course. At this elbow the River Welland joins the Witham, almost at right angles, and both flow together in one channel for about 4 miles, when the united streams again divide into two, one channel pursuing a north-easterly course, and skirting the coast for about 18 miles, till it reaches the ocean near Skegness. This channel is used by vessels going northwards. It increases in width from about a $\frac{1}{4}$ mile to $1\frac{1}{4}$ mile, but contracts again at its outlet to about $\frac{1}{4}$ mile. The depth also varies in nearly the same proportion, being at low-water spring-tides from 5 fathoms to 6 fathoms, where the channels separate, and decreasing to about $2\frac{1}{2}$ fathoms at the Outer Knock Buoy, its point of exit. The other channel, leaving the north-easterly direction, flows down what is termed the Maccaroni, making an acute angle with its former course; but after running in this direction for $1\frac{3}{4}$ mile, it doubles back up the 'Gat Channel' into Lynn Well. The depth of the water in the Maccaroni is from 1 fathom to 2 fathoms; in the 'Gat' it increases to 6 fathoms, and continues deep water all through Lynn Well. The length of the north course is about 20 miles, and by the south course for vessels going in the same direction it is about 7 miles longer. It is through these two channels that the waters of both the Witham and the Welland have to flow before reaching the sea. The greatest hindrance to the discharge of the waters occurs at the elbow before alluded to; here the Witham and Welland meeting and passing out of the confined channels through which they had been running, spread themselves over a wide and unconfined space, and so lose their velocity, and with it their power to move the sands and mud accumulated during the summer months. The deposit of silt at this point is also much increased by the stagnation caused by two rivers meeting almost at right angles. Owing also to the long winding course of the water of the Witham round the clay foreshore by Elbow Point, a distance of 4 miles (the direct course across this clay foreshore being only $2\frac{1}{4}$ miles.) there is a great loss of fall. Thus while the water at Hobhole Sluice, about 3 miles above this bar, is 7 feet deep at low water, and in Clay-hole, about 1 mile below Elbow Point, 10 feet; at the bar there is not more than 10 inches. (Plate 9, Section.)

At the same time the tide flowed 19 feet 6 inches at Clayhole above low-water mark, and 10 feet 11 inches at Hobhole sluice, showing a fall of 8 feet 7 inches in a course of about 4 miles. The removal of this bar, so as to obtain a greater fall for the waters, has been the aim of all the engineers who for the last one hundred and twenty years have been called in to report on

the state of the haven, either by the Drainage or by the Navigation Commissioners. The first to report on the matter was Mr. Kindersley, in 1750. He was followed by Captain Huddart, in 1793, Mr. Rennie, in 1800, and recently Mr. Hawkshaw. These have all recommended one course—the making of a new cut through the clay foreshore, about $1\frac{1}{4}$ mile in length, and confining the water to this channel, and the training of the Welland with fascine-work through the shifting sands to a junction with the Witham in Clayhole. By this means the course of the Witham would be shortened about $1\frac{3}{4}$ mile, and being confined by the embankments and fascine-work, would not have that great body of shifting sands to contend with, and would be at once carried into deep water at Clayhole. This would allow all the flood waters from the several sluices to be properly discharged, and give a general relief to the low lands of the Fens. It is estimated that by this scheme the head of water at Hobhole Sluice will be lowered 5 feet, at Maud Foster Sluice, the Black Sluice, and the Grand Sluice, from 2 feet to 3 feet, and in the Welland from 3 feet to 5 feet. In a Report made to the Witham Commissioners by their Engineer, it is recommended that this cut should be 130 feet wide, with slopes of four and a half to one; also that a bank $\frac{3}{4}$ mile long should be constructed across the present channel, the total expense for the Witham Channel being about sixty thousand pounds. For training the Welland into the same channel it was estimated it would take about a million and a half of thorn kids or faggots; and the cost of these and dredging the channel was put at twenty thousand pounds. By carrying out this plan, many acres of land, at present covered by the tide, would in course of time warp up and become good marsh land. Objections have been made to this scheme, that it would only be a temporary alleviation; that the sands and mud would deposit themselves at the end of the cut in Clayhole; and that the bar already existing at the end of the North Channel near Skegness would increase, and form a serious impediment to the navigation and the free discharge of the waters. It has been recommended that instead of making a direct cut through the foreshore to Clayhole, the waters should be trained by fascine-work through the sands in an easterly direction into the Gat Channel, and so into Lynn Well, where the waters of the Witham and the Welland would be brought to join those of the Nene and the Ouze, and all should flow through one basin into the sea. That this course would be far better for vessels, as giving them more sea-room, is evident; and at the same time it would be concentrating the whole of the waters of the four rivers, giving them additional scouring-power, and diminishing the size of the bay; but the cost would be much greater than that of the former plan.

In the year 1825, Sir John Rennie was consulted by the Har-

bour Commission as to the state of the haven, and he advised that the channel, which, between Skirbeck Church and Hobhole Sluice, took a very winding course, should be straightened by means of a new cut, 260 feet in width, and that along the whole course of the river the banks should be contracted, and the water confined to the channel. These works were carried out at a cost of about forty thousand pounds. To accomplish the contracting of the width of the river, where it exceeded that of the new cut, banks were built up of fascine-work, and the waters conducted between these parallel training-walls. The fascine-work consisted of thorn faggots, locally called 'kids,' the usual size being 6 feet long, and 3 feet round the band. Alternate layers of faggots and clay or sods were laid till the wall rose to a certain height above the adjoining sands, and in this state was left for some time. The warp carried by the tide gradually deposited itself on the sand at each side of the wall, when the wall was again raised, and this process continued till the land rose to such a height as only to be covered by spring tides. The accretion after this was so gradual, that samphire and other marine plants soon began to grow, giving place in time to grasses, forming good pasturage for sheep.

About thirty years after the commencement of the work, three hundred acres of this land were sold for ten thousand pounds, and embanked by the purchaser. Two other marshes were retained by the Commissioners; and last year the Author of this Paper, acting under instructions from the Commissioners, embanked these marshes, which were immediately let on lease at a rental of three hundred and ten pounds, the quantity of land, including foreshore and bank, being about one hundred and sixty acres. The cost of the bank was about fifteen pounds an acre, and it was constructed from the silt or mud of which the land consisted, covered with a facing on the haven side of clay and sods. Nearly a thousand acres of similar land on the banks of the Witham and the Welland have been taken in during the last two years, and thousands yet remain to be enclosed. In the year 1851, a company was formed, called the Lincolnshire Estuary Company, for the purpose of reclaiming from the sea and enclosing the whole of the lands from Wrangle, on the western side of the bay, to those of Gedney and Long Sutton, on the south and east, containing thirty thousand acres. This scheme also included the training of the Witham and the Welland through Boston Deeps to the North Sea. Owing to financial and other difficulties, it was not carried out, and the powers of the Act have been allowed to expire. It is a matter of the deepest regret that this should have been the case; it would have been a work of immense benefit to all the surrounding district, by improving the outlet of the drainage of the Fens, and adding to the resources of the district the produce of such a large tract of land, now barely

worth a few shillings per acre as grazing-land, but capable of growing, if reclaimed, from thirty to forty bushels of wheat to the acre.

The system of parallel training walls constructed of faggots, clay, and chalk has been adopted to a great extent in the rivers that drain the Fens, and has been found to answer the purpose of guiding the waters better than any other plan that has been tried. The silt or deposit settles down between the interstices of the faggots and gradually fills them, giving to the whole mass a weight and consistency capable of withstanding the opposing force of the tides. The branches of the faggots also interlace one within the other, and when the bottom on which they are laid is not sound, they settle down gradually, rendering them far superior to stone or other like material for use amongst silt and shifting sands.

To prove the utility of this method of training, it may be mentioned that, occasion having arisen about fourteen years ago to divert the course of the Witham at a point near the Hobhole Sluice, situate at its lower end, where, in times of flood, a body of water 250 feet in width, and 6 feet in depth will sometimes be running at the rate of 3 miles an hour, a jetty was made in 20 feet of water composed entirely of fascines, clay, and stones. The seat of the jetty was 25 feet wide, and it battered up on the river side to 10 feet at the top, being perpendicular at the back. The method of laying was as follows:—Two barges containing faggots and clay were made fast on each side of the intended wall; long poles were then driven down, the tops being made fast to the barges. The fascines were thrown into the water between these guiding poles, and on them clay at the rate of about 40 tons to 400 faggots. This process was continued until the faggots rose above the low-water line, when the barges were moved forward, and the same process continued. On the upper layers of faggots lumps of chalk or clunch were thrown in in addition to the clay, to weight the fascine work until it had settled down. This jetty was 200 yards long; it received the full impact of the stream, but yet it had stood without repairs up to the present time. The cost was about £5 per running yard, £3 being for materials, and £2 for labour. The fascines are made of thorns, the bundles being 6 feet in length and 3 feet in girth. Each fascine may be calculated with the clay to raise the work 9 inches in height, and three fascines will make a bank 6 feet in width. The thick ends of the boughs should all be put together, and the faggot tied with tarred rope-yarn. The cost in this locality has been £7 per thousand, six score being reckoned a hundred.

Several miles of training walls on the River Welland and on the Witham have been made in the manner described. Those on the latter river were laid in from 15 feet to 20 feet of water.

From the nature of the estuary through which these rivers have to be trained, the use of this fascine work enables the work of training to be carried on at a small cost as compared with the use of any other materials. The present bed of the river consists entirely of a deposit of silt, varying from 10 feet to 20 feet in depth. The training walls must of course rest on the clay below this deposit, and it is found in practice that as the walls are advanced, the tides scour deep holes at the end of the work, leaving the clay bare; but even if the whole of the silt be not washed away, and the fascines are dropped on it, they settle gradually down without falling out of the regular line; all that is necessary is to add fresh layers on the top as the wall subsides.

The practice is generally to make the top course about 6 feet wide, which requires three fascines in width, the ends overlapping one another. The width increases at 4 feet to four fascines, and at 10 feet to five fascines, or 20 feet. On each course there is a layer of 6 inches of clay, and the top is covered with thick marsh sods, the whole being carried up to about half-tide level. The cost per mile of training wall varies for depths of from 8 feet up to 20 feet, from £2,500 to £7,000.

In cases where it has been necessary to guide the direction of the waters, either by taking the bends out of the winding bank, or giving it a fresh line, spurs or groins have been used. These spurs are made of timber and faggots, built in the form of the letter V, the thin end of the V presenting itself to the stream, and the thick end joining the bank or shore, the angle varying with the direction the water is intended to take. These are placed at certain intervals apart, but wherever a spur is placed, the water striking against the projection, makes numerous eddies and whirlpools, forming deep holes in one part, and sand-banks in another, an inconvenience from which the parallel ramparts or walls of fascines are free. When it is intended that the ground from which the water is driven shall accrete, walls are far preferable to spurs, as holding up the sides of the stream, and allowing a firm base to form behind them, on which ultimately the bank for the exclusion of the waters from the land can be formed.

Conclusion.

A brief review of the general results of the enclosure of the Fens will conclude this Paper.

The state of the level previous to the drainage has been already described, as being nothing more than a vast morass; the few scattered inhabitants living a wretched half-savage life, and subject to ague, rheumatism, and similar diseases. Even now the bad name which this part of the country deserved in those days still to a certain degree remains. A general impression

prevails amongst those who have never visited the county, that Lincolnshire is one of the most uninteresting and miserable places on the face of the earth, and that owing to its flatness the atmosphere is perpetually damp and unhealthy, and the inhabitants martyrs to ague and low fever. A visit to the Fens would at once dispel this delusion. A more highly cultivated district, or better land is not to be found in England. As the traveller journeys along the roads, he will see on every side, as far as his eye can reach, nothing but rich fields of corn or pasture, dotted here and there with farmhouses, and, if it is in the winter season, well filled stock-yards, and large stacks of corn; the occasional canal or drain bearing its testimony to the skill that has made the land what it is. And although there may be a want of variety of scenery, the loss is amply compensated by the richness of the crops, and a feeling of satisfaction that not a yard of land is wasted, but that the well-trimmed hedges, and the square fields, if devoid of the picturesque, are eminently adapted for growing the staple product of the country in its greatest perfection. He will find grazing in the fields (as Cobbett once remarked) "the largest beasts, and the fattest sheep to be seen from John o'Groat's to the Land's End;" and will recognise in the horses, the stock from which come those immense animals that London brewers pride themselves in keeping; the stalwart size and contented look of the labourers will convince him of the healthiness of the climate; and if he stop to observe the tombstones in the churchyards, he will find that people live as long or longer in the Fens than in what are considered more favoured localities. Further, as a proof of the general healthiness of the Fen climate, it may be mentioned that in Boston, the principal town of the Fens, the death-rate is under twenty in the thousand, and that, during the year 1865, out of one hundred and ninety-three deaths of adults, which were recorded on the parish books, their average age was sixty-one years eight months, and that seventy-seven of these were over seventy years of age, and eight between ninety and a hundred.

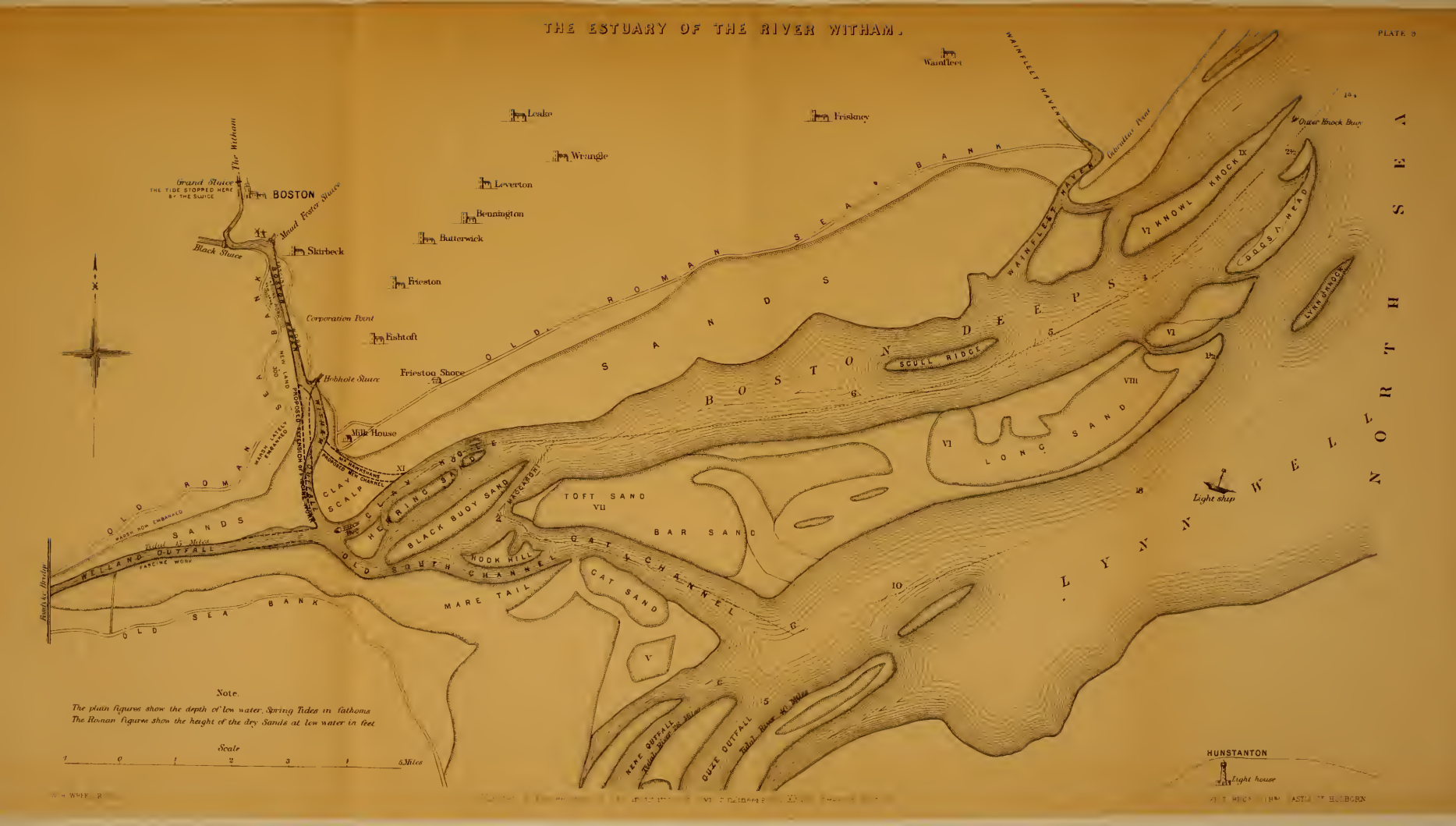
The general appearance and prosperity of this large tract of land, equal in extent to many counties, when contrasted with what it was a century ago, are a striking proof of the ingenuity and industry of man, and reflect the highest credit on the skill of the engineer, and the enterprise of the people.

The communication is accompanied by several plans and sections, from which Plates 8 and 9 have been compiled.

[Mr. Wheeler

PLAN OF THE FENS OF LINCOLNSHIRE DRAINING BY THIS RIVER.
THIRD DISTRICT
FOURTH DISTRICT
FIFTH DISTRICT
SECOND DISTRICT
FIRST DISTRICT
WASHINGBORO FEN
BRANSTON FEN
POTTERHANWORTH FEN
HOUSTON FEN
DUNSTON FEN
NETHERIGGHAM FEN
BLANKNEY FEN
LINWOOD FEN
MARTIN FEN
WALCOT FEN
BILLINGHAY FEN
DIGBY FEN
RUSKINGTON FEN
NORTH KYME FEN
SOUTH KYME FEN
EWERBY FEN
HECKINGTON FEN
SLEAFORD
BOSTON AND SLEAFORD RAILWAY
HALE FEN
SWATON FEN
DONINGTON FEN
HELPRINGHAM FEN
HORBLING FEN
BILLINGBOROUGH FEN
QUADRING FEN
NAVLAND FEN
SURFLEET FEN
POINTON FEN
COSBERTON FEN
DUNSBY FEN
PINCHBECK FEN
MACONDY FEN
DYKE FEN
BOURNE FEN
DEEPING FEN
WILDMORE FEN
BOSTON WEST FEN
SUTTERTON FEN
BOSTON
WEST FEN
EAST FEN
SPALDING
HOLBEACH
SANDS
THE WASH
BOSTON DEEPS
LINCOLN
Washingtons
Brauston
Bardney
Stixwould
Dunston
Mothernham
Timberland
Blankney
Scopwick
Kirkby Green
Roulston
Digby
Dorrington
Ruskington
Anwick
Sleaford
Ewerby
Great Hale
Helpringham
Swaton
Folkingham
Horbling
Billinghamough
Dowdby
Rippingale
Dunsby
Bazenby
Morton
Bourne
Timberland
Billinghay
North Kyme
South Kyme
Heckington
Swineshead
Becker
Donington
Quadring
Gosberton
Surfleet
Pinchbeck
Spalding
Deeping
Coningsby
New Bolingbroke
Revesby
Hogsthy
Wainfleet
Friskney
Wrangle
Leake
Leverton
Benington
Butterwick
Friesthorpe
Fishtoft
Wyberton
Frampton
Kirton
Algarkirk
Sutterton
Wigtoft
Gosberton
Quadring
Donington
Swineshead
Tattershall Bridge
Cowbit
Surfleet Bridge
Fosdyke Bridge
Boston
Skirbeck
Haven
Grand Sluice
Black Sluice
Maud Foster Sluice
Cowbit Bridge
Fosdyke Bridge
Boston Haven
Scalby Beach
Kilburn Beach
Clay Bed
Rivers
Miles
SECTION OF RIVER WITHAM FROM LINCOLN TO THE ESTUARY.

THE ESTUARY OF THE RIVER WITHAM.



Note.

The plain figures show the depth of low water Spring Tides in fathoms
The Roman figures show the height of the dry Sands at low water in feet

Scale

1 0 1 2 3 4 5 Miles

Mr. Wheeler remarked that since the Paper was written there had been an exceedingly dry summer, and the effect of the sluice on the Witham was more marked than before. After early spring no water had passed through the town of Boston, and the silt had accumulated to a depth of 11 feet, sufficient to prevent the neap tides from reaching the town. Not only was the navigation of the river almost suspended, from the impossibility of getting vessels up, but the whole of the drainage of the Fens was also stopped. The water on the previous day (November 30th, 1868), was just level with the upper side of the doors, and it would require a height of water of 13 feet before the accumulated silt could be carried away. The sluice was situated about 8 miles up the river. When the Fen rivers were in their natural state there was no deposit. Thus, in the Welland, at the same distance from the mouth there was no deposit, and at Spalding, where the tides reached 13 miles up the river, the silt was only 2 feet 6 inches thick, whereas in the Witham the deposit of silt was, as he had stated, 11 feet, all of which would require to be removed before the river was restored to its normal condition.

Although up to the end of October the rainfall had been only about 1 inch below the average, yet May, June, and July were very dry months; and all the rain since then had been absorbed by the Fens, and no water had flowed down the river.

The river Witham was trained between fascine walls as far as Hobhole; beyond that the river ran through shifting sands. The flood tide came up at the rate of about 4 miles an hour for two hours, and drove the silt up to the Grand Sluice. The ebb lasted ten hours, and during that time the silt settled. The accumulation of silt would probably be removed by the fresh water floods in the winter. In 1863 there was a depth of 9 feet 6 inches of silt, and in 1864 of 11 feet, all of which was scoured out by the winter floods. In the Welland there was a back scour of tidal water, but not in the Witham.

Mr. Vignoles, Vice-President, said it appeared that there existed, as it were, a struggle between maintaining the drainage of the country and the navigation of the port. He thought it was impossible, at certain distances from the sea, to combine the perfection of drainage with the perfection of navigation: one of the two must yield to the other. There might be a point at which the two could be combined: but, looking at the records of this country and of Italy, where former seaports were now far inland, owing to the accumulations of mud at the mouths of the rivers, he thought it could only be accomplished to a limited extent. In the estuary of the river Witham the drainage had been improved, and thereby much valuable land had been brought under profitable cultivation; but Boston and other ports had suffered, and would probably

continue to suffer. If the sluice were removed, the tide would no doubt wash away the accumulation of silt, but in other respects its removal would be to the detriment of the drainage. An unprofitable expenditure would be incurred in attempting to improve the navigation to Boston, and the minor channels leading to other places. At present the drainage of the country had been brought to a high state of perfection. He repeated the opinion that the combination of effective drainage and the perfection of navigation were incompatible.

Mr. Hemans considered the leading principle enunciated in the Paper was, that a sluice was objectionable at the mouth of a tidal drainage river: but many sluices were situated on tidal rivers where an accumulation of silt did not take place, or at least not to the same extent; otherwise it would be impossible to continue the use of such sluices. If the sluices which protected low-lying lands from the inroads of the tide were removed, either the lands must be submerged, or the rivers must be embanked for the whole length to which the tide flowed. In the latter case the expense would probably in many instances be greater than the operation was worth; and as there were many rivers without longitudinal embankments to prevent the encroachments on the land, though there might be embankments on the coast, it was clear that a sluice in such cases was suitable.

Mr. Brereton said an endeavour had been made to show that the sluice had benefited the drainage, although at the expense of the navigation. But so far from there having been any drainage through the sluice, it had been dammed up for months, and silt had been deposited against the doors, on the outside, to the level of high water of neap tides—a level not yet equalled by the accumulated inland drainage; and the navigation to Boston by the river could only be available for craft drawing a depth of water not exceeding the difference between the levels of high water of neap and of spring tides. To remove from the bed 10 feet or 12 feet of mud by natural scour, the inland waters must rise nearly to the level of high-water spring tides, but the water collected during several months had only reached about two-thirds of that height as yet.

Mr. A. Giles, speaking without personal knowledge of the locality, suggested that, if there was not sufficient scour to remove the mud, the gates should be lifted occasionally at high water, so as to pound a portion of the tide, and be opened at the ebb to let the water out. If the sluice were done away with, considerable expense must be incurred in making the banks stronger, to resist the influx and scour of the tide.

Mr. Cubitt, Vice-President, said the reason why the draw-gates of the Grand Sluice were not opened to allow of the accumulation being cleared away below was that, in seasons of drought, the

water could not be spared, owing to its being required for the purposes of navigation and for the supply of water for irrigating the land.

Mr. R. C. May said that in 1853, he constructed the outfall of the Walland and Denge Marshes at 'Jury's Gut,' or 'Jew's Gap,' in Kent, and placed a reservoir or tidal pen, at the sea end of which were draw-gates and at the land end self-acting tidal doors. The tidal water thus penned-in formed a sufficient scour to keep the outfall quite clear. In this case it was not silt that had to be contended with, but the accumulation of shingle and sand which travelled from west to east with the tide on that coast.

Mr. Wheeler remarked that the sluice across the river was, no doubt, the cause of the accumulation of silt. This river was not comparable with the drains in Holland. The sluices erected in Holland were at the mouth: this sluice was 8 miles up the Witham. Of the four large rivers of the district—the Nene, the Ouze, the Welland, and the Witham—the first three, which had no sluices, were in excellent condition. The land above the sluice had been embanked, and the banks had been strengthened by deepening the river; he thought they were quite strong enough to withstand the tide flowing up the river. As soon as there was a head of water above the sill of the sluice of about 12 feet, and he believed it was now nearly at that point, the silt on the lower side of the door would be loosened, and on the doors being opened the silt would be washed away. He had suggested the admission of a certain quantity of tidal water up the Witham. He thought no remedy would be effectual, except the Witham were put in the same condition as the Nene and the other Fen rivers.

Mr. Hawksley, Vice-President, remarked that the Ouze, the largest of the four rivers mentioned by the Author, had a remarkable sluice upon it at a distance of 6 miles or 8 miles above the town of Lynn. It had a peculiar effect upon the régime of that river, which was not stopped up by deposits in the way the Boston river was. He mentioned this because he was desirous that no misapprehension of facts should take place on a question of such importance as the one raised by the Paper.

Mr. Wheeler remarked, that the sluice on the Ouze was a long way from the mouth, and in a different position to the sluice on the Witham. The Denver Sluice had been condemned ever since it was put up. On all artificial drains, such as the Black Sluice, and the other drains on the Witham, which were not tidal streams, sluices were necessary and could not be dispensed with. In reply to various inquiries, he stated that the aggregate power of the pumping engines was 350 H.P., and they were under the control of numerous bodies of internal drainage commissioners. If the Grand Sluice were removed, and the training of the river continued

2 miles beyond its present limits, *i. e.*, from Hobhole Sluice to Elbow Buoy, nearly the whole of the engine power, not only above but in the districts discharging their waters below the Grand Sluice, could be dispensed with. The sill of the Grand Sluice was about 5 feet above the present bed of the river at Elbow Buoy, off the Scalp. The ordinary level of the water in the winter would be about 5 feet above the sill of the Grand Sluice, floods about 9 feet, and very high floods 13 feet. The inclination of the surface at ordinary low-water spring tides varied from 8 inches to 1 foot according to the state of the river. The silt began to be removed immediately there was a flow of fresh water. One of the doors had been opened very recently, and the water was now conveying the silt away. In very wet winters, followed by a wet spring, the river would be scoured out to its natural bottom; but, in ordinary winters, a deposit of silt would still remain varying from 2 feet to 3 feet in depth. Heavy freshes would run at the rate of about 3 miles an hour; but the silt was scoured away with a much less rapid current, say 1 mile per hour.

Mr. T. Login believed the facts given in the Paper bore out the theory he entertained with regard to the transporting power of water. He would give a few examples of what he had himself seen in India. In 1855-56 he reported on the navigation of the chief rivers in Burmah, the Irrawadi, and the Sittang. The former discharged its water at the rate of upwards of 700,000 cubic feet per second during floods, and was navigable for sea-going steamers to the frontier, while the latter, which probably did not discharge one-tenth of that volume of fresh water, was so dangerous that on the only occasion of Europeans attempting to enter its mouth nearly all the boat's crew were drowned.

The rise and fall of the Bassien branch of the river Irrawadi was only 9 feet, and of the Rangoon branch 21 feet; whereas the range of tide in the Sittang river was estimated to be from 35 feet to 37 feet between the high-water flood-tide mark in the dry season and low water at the mouth of the river. He attributed the difference in the character of these rivers to the quality of the soil brought down by them, which in the Irrawadi was chiefly mud and in the Sittang sand. He believed that in England, by the extension of cultivation of the land and improved drainage, floods were increased, and carried a larger proportion of soil from the ploughed land into the rivers, and in that way the navigation near the sea was injured.

Some years ago he had noticed a landslip on the right bank of the Ganges, near Rajmahal. The land had slipped down almost 20 feet, but the perpendicularity of a number of palm trees on it had not been disturbed. Again, on the Bassien river, in Burmah, 80 miles inland, he had found a hole 120 feet deep, or upwards of

100 feet below the sea level. Now rivers, such as the Ganges and the Irrawadi, were very liable to change their course, so that what might appear to require ages for its accomplishment might be the work of a single flood. Trees might be found standing 20 feet or 30 feet below the surface, or relics of man 100 feet below the level of the sea far inland: therefore caution should be observed in attributing the finding of these relics—anchors, boats, &c.—to the sinking of the deltas or the upheaval of the land, when the phenomena might be due to the change in the course of a river.

As to the necessity for keeping springs of water below the surface, in the year 1860 he had had the supervision of the irrigation of the Puttree Valley added to his other duties. The natives formerly were in the habit of damming up the water in the streams 10 feet or 12 feet, and causing it to flow over the land; in consequence the spring level was raised. He found that when the level of spring water was more than 18 inches below the surface in years of drought, the crops were benefited by irrigation; but as the water approached nearer the surface, the crops became more and more stunted; and at 12 inches from the surface the crops disappeared altogether and then gave place to grass. Where the water covered the ground, jungle and reeds grew to a height which afforded cover for elephants and tigers.[1]

No doubt the silt could be got rid of, and the navigation of the river Witham be improved, by the removal of the Grand Sluice, but by admitting the tidal water the drainage of the Fens might be endangered. By holding up the spring levels, possibly the same injury might occur as in India, and the Fens, which of late years had been so much improved in climate and cultivation, might fall back into their former state. He would not venture to give an opinion as to how the navigation should be carried out; but he suggested that, if separate navigation was required, the level of the surface of the water in the canal should be below the reduced spring level in the Fens, and that the drainage of the Fens should not be connected with the canal, but passed under it by syphons.

With regard to the annual silting up below the Grand Sluice, he could give a similar example on a larger scale. The Pegu river, which fell into the Rangoon river just below Rangoon, was so narrow at the town of Pegu that, although there was a depth of water in the river during the rains sufficient to float a man-of-war, yet, in turning the steamer, the stern had to be made fast to the bank, to allow the vessel to swing round with the stream; whereas only 20 miles distant was the Sittang, a river 5 miles broad, but

[1] In some parts of this valley an efflorescent salt covered the ground, having the appearance of hoar frost, and rendering the soil barren.

so shallow that its navigation was difficult, indeed dangerous, for boats when the tide was out, even during the rains. A little below Pegu, these two rivers were connected by the Pyn Kyoung creek, through which during the rains loaded boats could pass, but not in the dry season. He took levels in that direction in March, 1856, at which time during spring tides the silt was thrown up to such a height, that at high water of neap tides a cart could be driven over the bed of the creek, which was nearly level with the banks. This was due to the ' bore ' which passed up the Sittang every tide, and which he witnessed at the Sittang end of the creek in September, 1855. He heard a distant sound seawards, and a few moments after saw breakers on the horizon, several miles long. In less than a quarter of an hour the water was rushing past at the rate of 9 miles or 10 miles an hour, and the creek was filled to a depth of 11 feet. The tide flowed for about two hours, but did not rise after the first rush of the ' bore ' more than 1 foot or 2 feet, and the total rise and fall here was only about 12 feet, but near the sea it must have been much greater. This afforded an example of the silting up of a navigable stream every year, as happened below the Grand Sluice on a much smaller scale. On the Sittang, the current had a velocity of 10 miles an hour, and there was no scour but a silting up of the bed; whereas on the Witham there was a tide with a velocity of 4 miles an hour, carrying with it earthy matter, which was deposited as it gradually came to rest, but which would all disappear again when the fresh waters came down, as observed in Pyn Kyoung creek. He had already remarked that the effect of increasing the drainage was to augment the floods. In such cases the duration of the flood should be lengthened by reservoirs to hold the water up, which might be used for sanitary purposes, or for water power. If used for sanitary purposes, he recommended what was called in India the system of Dhall irrigation; that was keeping the surface water in the channels which conveyed the sewage water always below the surface of the country, so as not to raise the level of the spring water in the Fens; or that the sewage should be conveyed in close pipes under pressure.

Mr. Murray stated that the river Witham rose on the northern borders of the county of Rutland about 10 miles south of Grantham, and comprised a water-shed between Sleaford on the east and near Newark on the west to Lincoln of about 250 square miles. The waters of this river were divided at Lincoln, and during floods about one-third of the discharge passed northwards by the Fosdyke into the Trent, at Torksey; while the remaining two-thirds were discharged by the Sencil Dyke and the main channel by Lincoln and Boston into the Estuary or Great Wash, a course of about 36 miles. Boston was situated about 4 miles

above this Estuary, and the Grand Sluice was placed across the river Witham in 1762, a short distance above the town, whereby the tidal waters were excluded from the channel between Boston and Lincoln. The late Mr. Rennie, in 1802, proposed raising and strengthening the embankments of the Witham to the city of Lincoln; scouring out and deepening the parts requiring it; rebuilding the locks; and making a capacious cut above Lincoln with draw-gates thereon to carry off the floods. He also proposed to embank the river Till, and to make drains therefrom to discharge its floods into the Witham; and to supply the Fosdyke lock with water, by pumping it from the Trent: thus turning the whole waters of the Witham down its natural channel in the summer season, as well as during floods, for the purpose of keeping the Grand Sluice open, and preventing the accumulation of silt in Boston Haven.

An Act was obtained in 1812, constituting the Company of Proprietors of the Witham Navigation and another body, called the General Commissioners of Drainage. In 1814, the South Delph was formed between Sencil Dyke and Horsley Deeps, but the banks were not completed till 1830 or 1832. The Great Northern Railway Company in 1847 took upon themselves a complete transfer of everything from the Navigation Proprietors: and in consequence of neglecting to cleanse and deepen the channel downwards to the Grand Sluice, the flood-waters were not permitted to run with their proper efficiency. This had been rectified by the works of 1864, as carried out by Mr. Hawkshaw.

He did not agree in opinion with Mr. Hawkshaw, that the Grand Sluice should be removed. A sluice was necessary when the fall and quantity of fresh water of a river was small; otherwise, were the tidal water admitted, impregnated with silt, it would be deposited in its upward course, which the force of the ebb would be unable to remove. He granted that the harbour of Boston might at first be benefited by the greater velocity of the tidal stream to fill the river above; but on the ebb, unless aided by a body of fresh water, and by floods, the effects would certainly not be beneficial between Bardney and the Grand Sluice, and the river below the sluice in course of time would also become deteriorated. He, however, quite agreed that if the outfall below Boston were deepened and properly trained, the most beneficial effects would be produced; and would probably in time enable the lowering of the sills of the Grand Sluice, and the partial admission of the tide through slackers in the gates, retaining the water for a short period after high water, and assisting the tidal scour downwards. This might possibly require gates at the mouths of the subsidiary rivers and drains, to retain the fresh water for the supply of cattle feeding on the lowlands.

In improving the outfalls of the rivers Witham and Welland, it was important to consider the estuary into which they discharged their waters. Lynn Deeps was the natural receptacle of the rivers Nene and Ouze; but it was doubtful whether the former rivers should be trained into it, as recommended in the Norfolk Estuary scheme, which could only be done at great expense; whereas if conducted by artificial means into Boston Deeps, the risk would be moderate, and attended with less cost.

The flood tide of the North Sea ran southward from Flamborough Head nearly direct into Lynn Deeps, where it rose 23 feet at ordinary springs; from thence it ran into the different rivers at the head of the estuary, making the range of flood at Lynn 18 feet, while at Boston the range was only 12 feet. The Norfolk side of the estuary was composed of a mass of shifting sands, while the opposite, or Lincoln shore, had a long tract of deep water running parallel to it, called Boston Deeps, separated from Lynn Deeps by the Roger and Long sands. At the northern end of Boston Deeps there was a bar with little more than a fathom of water upon it at low water. In the deepest part of the Deeps there were 7 fathoms, and opposite to it, in Lynn Well, there was a depth of 27 fathoms. Tidal action alone maintained Boston Deeps. The main set of the North Sea penetrating the shoals lying off the coast between Norfolk and Lincolnshire had scoured out the Inner Silver Pit many miles in length; and the set continued between the Inner Dowsing and Docking banks into Lynn Deeps. Running here with greater velocity than into Boston Deeps, it soon attained a higher elevation, and when the Roger and Long sands were covered, the tide set over them nearly at right angles into Boston Deeps like an overfall. On the return of the ebb, there being no bar to Lynn Deeps, the water fell rapidly, and when the sands were left dry, the water in Boston Deeps found its way to sea over its own bar; hence maintaining this long tract of deep water parallel to the Lincoln shore. It was evident, therefore, that in the present state of things it would be impracticable to warp up this Deep, as proposed in the Norfolk Estuary scheme: and it appeared reasonable that, by training the rivers Witham and Welland into its upper end, no injury would accrue, excepting the possibility of a bar being formed at the point of junction with deep water.

As the outfalls of the rivers Ouze and Nene had been vastly improved, he might be permitted to make a few observations on the works executed on the former river, trusting that some one better acquainted with those of the Nene would explain them. The New Bedford or Hundred-Foot River having been made in 1652, the upland waters of Huntingdonshire were brought from Earith in a direct line to the river Ouze at Denver, a distance of about 20

miles; and as the floods of Cambridgeshire were longer in arriving at the same point, it was necessary to prevent any over-riding of the waters. Denver Sluice was therefore erected in 1653; and then the Lynn people began to complain of want of depth in the harbour. The sluice was blown up in 1713. When it was down the neap tides did not reach Denver, while ordinary springs only rose about 2 feet, the water being lost in the South Level. It was rebuilt in 1746 with a clear waterway of 86 feet, and when the water was at the highest, according to Watté, the sectional area was 1,500 square feet.

The great success of Kinderley's Cut, below Wisbeach, gave rise to another project of Kinderley in 1724, viz. the Eau Brink Cut; but it was not till 1795 that an Act of Parliament was obtained for its formation, and, so great was the opposition to the scheme, that it was not completed till the year 1821. Its length was about 3 miles, while the old circuitous and wide course of the river was about 6 miles. It was widened and improved in 1825. Coincident with the formation of the Eau Brink Cut, Denver Sluice was rebuilt, the sills being laid 5 feet 4 inches lower than the old drainage sills. It had three openings for drainage, each 18 feet wide, and one for navigation, also 18 feet wide. Between Denver and the head of the New Cut, a distance of 10 miles, the bed was scoured to a depth corresponding with the Cut. The effect on the drainage of the country was considerable. By observations made by Sir John Rennie in 1838, compared with those made by Watté in 1791, the low-water line was depressed at Denver 4 feet 2 inches, at the head of the Cut 6 feet 7 inches, and at Lynn Ferry 1 foot 7 inches. In consequence of this lowering of the water surface in the River Ouze, the Middle Level drain was undertaken. It was opened in 1848, with a sluice at its lower end, near the head of the Eau Brink Cut. The drain was deepened to its full extent in 1857. But in 1862 the sluice blew up, and the tide inundated a large district of the lowlands of Marshland.

In 1849 the Norfolk Estuary Bill was in Parliament. It was proposed to make a new cut across the marshes from below Lynn to Howard's Sluice, about 2 miles in length, and to train the river for about the same distance below it, thereby discharging the waters of the Ouze into the upper end of Lynn Deeps. Notwithstanding the great opposition to this measure, it was soon afterwards carried into execution. It was made 250 feet wide at the level of low water, increasing 25 feet in width per mile downwards, so that at the level of high water, on leaving Lynn harbour, it was 410 feet wide, and at Howard's Sluice it was 460 feet wide. It was originally 20 feet deep at ordinary spring tides, but the bed had been deepened by natural scour. The effect on the drainage of the country had been great. By observations made in 1855, and com-

pared with those above mentioned in 1838, the low water at ordinary spring tides had been depressed at Denver Sluice about 9 inches, at the head of the Eau Brink Cut 2 feet 9 inches, and at Lynn Ferry 3 feet 9 inches. Thus, by the formation of these two important works, the low-water line had been depressed at Denver Sluice 4 feet 11 inches, at the head of the Eau Brink Cut 9 feet 4 inches, and at Lynn Ferry 5 feet 4 inches, or an average of 6 feet 6 inches.

The fall of the low-water line between Denver Sluice and the head of the Eau Brink Cut was ascertained to be in 1855	7·113	inches per mile.
Through the Eau Brink Cut	3·844	„ „
From ditto to Lynn Ferry	10·400	„ „
Through the Estuary Cut	7·582	„ „

Showing that the Eau Brink Cut might still be scoured, or made deeper than it was found to be in 1855.

Mr. Charles Frow, of Holbeach, had paid particular attention to the drainage of the Witham; and early in the year 1861 he had suggested a plan for the improvement of the outfall, which was repeated in a report prepared for the Boston Harbour Commissioners in May, 1864, and again in a map of the district he published in 1866, in opposition to a previous project, strongly recommended in 1860, by which it was intended to lead the water from Hobhole Sluice to Clayhole in a circuitous course. The estimate for carrying out this work, for cutting the channel across the Clays and the Welland Outfall, somewhat exceeded £100,000; but he thought it was inadequate, as it would afterwards have been necessary to secure the sides. However, he suggested that the channel should be trained with fascines through the sands, along the west side of and avoiding the Clays, which would cost only £20,000, and for the Welland £10,000.

At that time few people agreed with his views. In fact, the plan, previously projected by the Estuary Company, was generally regarded with favour by the inhabitants of the locality and the Engineers of the day; but now his project was thought so much of, that the Author of the Paper had adopted it.

In the line proposed to be cut across the Scalp Clays, the ground was soft clay to the level of low water; below that there was hard clay difficult to excavate, and it could not be scoured to a deep channel. It was, in fact, the Oxford clay. This was still found at Clayhole at low water, and under the Herring Sand.

In 1864, he was employed by the Boston Harbour Commissioners to report upon the feasibility of maintaining the straight channel he had before proposed; and on making borings he found the depth of sand so considerable, that a channel deep enough for navigation and for drainage might have been scoured by embanking the sides

with fascines, and contracting the current so as to scour away this sand. This was the practice of the district, and answered extremely well; in fact, the Welland had been so treated over a length of 3 miles. The unguided portion of this channel would have been 5 miles in length, and would have led in a straight line to Lynn Deeps. Nor would there have been danger of silt blocking the channel. The outfall of the river Lynn passed through a length of 7 miles of sands in which there were no guide banks; yet it had not silted up, and the same might be said of the Nene; and the Witham and the Welland combined would have kept their course clear. At the same time he advocated, as he had suggested in 1861, the removal of the Grand Sluice, whereupon the Boston Harbour Commissioners consulted Mr. Hawkshaw, who agreed that the removal of the Grand Sluice would effect a great improvement, and, in fact, was a necessary work. However, it was not carried out, and centrifugal pumping engines of 180 H.P. were erected in the East Fen, to pump the water from the lower lands into the other portion of the Fen, so that it might pass away over the high sands that were lodged in the river outfall. The levels of the lands where the pumping operations had been applied were, he believed, from 7 feet to 12 feet above the sill of the outfall sluice, so that the Fen might have been drained by gravitation. The cost of the erection of those pumps was likely to delay the removal of the Grand Sluice for want of funds. This sluice was 5 miles distant from the outlet. The flow of the tide up the Welland extended about 15 miles, and in ordinary seasons the rise of the tide was from 3 feet to 4 feet greater than in the Witham; because the admission of tidal water was larger, and the bottom was 3 feet or 4 feet lower than in the Witham, although there was less backwater. If the Grand Sluice were removed, and the tide allowed to pass up the Witham freely, the volume of water would be so much increased that it would thoroughly clear out the sands. It would be necessary to raise and secure the banks of the river for a short distance, and to alter the position of some sluices, to provide for a supply of fresh water and preserve the navigation. The clearing away of the Grand Sluice would insure the drainage of the Fens by gravitation instead of by pumping. Then, again, the constant flux and reflux of the tide would keep the sands lifted by the water in continual motion, and if any did accumulate, the heaviest portion would be deposited first, and in the lower part of the Haven, where they would be removed by every ebb tide. A short time since a dam was put across the river Nene near the town of Wisbeach, which was 10 miles farther from the outfall than the Grand Sluice. Soon the river was comparatively blocked up, though the obstruction was so far distant from the outlet. The dam caused the tide

to 'head' up, and rise higher than formerly where the dam was placed, and, saturating the earth at a higher level, broke down the slopes of the embankments. He advised the removal of the dam, and, after Mr. Page had been consulted, this was done, and the river being tidal for about 36 miles, had reverted to its former condition. It ebbed from 8 feet to 9 feet lower than the Witham in ordinary seasons, taking a point 7 miles up each river; and therefore he contended it would be an advantage to remove the Grand Sluice, when the Witham would be a tidal river for upwards of 30 miles. There was no fear of the banks being scoured away, as the bed of the river was of hard Oxford clay.

The outcrop of the clay formed the eastern boundary of the river Witham, which was prevented passing into the Fens by the ridge, along the side of which it had scoured a channel. This channel could not be maintained at a sufficient depth at the outfall by scour unless it was conducted through the sands. To cut through the Clays, and afterwards to secure the sides, would involve a great expense, and at Clayhole the hard clay was at or near the level of low water; whereas towards the Scalp reach and South Channel the depth of water at low water at a similar distance was from 10 feet to 30 feet. He believed the boulder and other compact clays had determined the courses of the rivers and lines of drainage of the great levels of the Fens. A clay ridge, on which were situated Stickney and Sibsey, divided the West Fen from the East Fen; and he believed the northern drift and clay formed the boundary between the original Estuary and the Fens. In the bed of the Estuary the clay was found at the depth of 100 feet or more in some parts; at Hobhole it was 20 feet to 30 feet below high water; at Clayhole it lay at a depth of about 20 feet only; and at the Scalp, where the cut was formerly proposed, it was slightly above 20 feet below high water, dipping rapidly towards the west and south. The Clays, therefore, protected the outfall; and if, as had been frequently proposed, a cut had been made through them, the natural protection of the outfall would have been thereby destroyed. At Boston, a bed of sand from 1 foot to 3 feet thick rested on the Oxford clay about 18 feet below the surface, and on the sand was a submerged forest. The Author had referred to men's shoes and a smith's forge being found at this level, and from that inferred that the Romans were there at the time the land was at a level 18 feet lower than at present. But the Roman embankments were made ages later. At Clayhole and along the coast of Lincolnshire there was a stratum of peat containing oak trees, and upon that peat in some parts about 18 feet, and in other parts 40 feet and upwards of various deposits, comprising clay, both stratified and unstratified, then peat, clay, and recently deposited sea sand. The northern drift and boulder clays, in patches and mounds,

were deposited on the subsidence of the coast. The boulder clay was superposed by a bed of sand with strata of various clays thereon, and the remains of another forest were found among the strata. Some catastrophe had overthrown all the trees of the lower forest with their heads towards the west; and on it there lay marine and other strata, and again on these another stratum or two of forest peat containing remains of trees of different descriptions. From this it would appear that there had been two or three distinct changes of level of the ground, and he conceived it might be possible, by comparing the quantity of each deposit, to arrive at an approximate estimate of the period of the northern drift and boulder clay deposits. The Roman bank which crossed the parish of Holbeach was considered to have been erected about the year 300. At present there was a breadth of about 7 miles of enclosed marshes in front of that point, so that the marsh had here increased in breadth at the rate of about half a mile in a century; and there was a breadth of about 3 miles of recently deposited sands between the Roman bank and the clay deposits. These clays were variously composed, and at a different tidal level; and the calculation led to the inference, that it was at least thirty thousand years since the last change in the relative levels of the land and the tidal waters of the Estuary. Previously the prevailing deposits were clays, not sands as at present. Taking this as the basis of calculation, he thought that the periods of the forests and of the northern drift deposits might be traced approximately. But at the same time this formation of marsh land showed that the sea-wall of the Romans was built upon the present surface, and not 18 feet lower, as implied by the Author.

He had ascertained, by taking levels, that the lowest lands in the Fens up the Witham were about 7 feet higher than corresponding fen lands up the Nene, at equal distances from their respective outlets. Yet the lands by the Nene were drained by gravitation, while the higher lands by the Witham were drained by pumping, at an estimated cost of £3,500 per annum. The necessity for this might fairly be attributed mainly to the Grand Sluice stopping up the river; and the defective state of the outfall caused the drainage by sluices discharging into the lower parts of the river Witham to be obstructed.

For comparing low water at the outfalls of the rivers Ouze, Nene, Welland, and Witham, tidal observations had been taken at about 13 miles above the confluence of the rivers in the Estuary, and, after being reduced to a common datum, 100 feet below Ordnance datum, were as follows:—

1866, November.	Ouze, Free Bridge.	Nene, North Level.	Welland, Fosdyke.	Witham, Black Sluice.	Witham, Hobhole.
	Feet.	Feet.	Feet.	Feet.	Feet.
Average . . .	94·43	95·13	99·75	103·83	100·42
Maximum. . .	96·75	98·12	100·25	104·90	101·25
Minimum . . .	93·50	94·48	99·25	103·00	99·67

From this it would be seen, that the level of low water in the Witham was nearly 9 feet higher than in the Nene, whereas it might be at least equal, as local circumstances were more favourable for the Witham.

For calculating the respective rates of fall per mile in each outfall, low water was assumed on an average of tides to be 90 feet above datum at a distance of 7 miles from each of the tidal gauges. At the confluence of the rivers low water probably averaged 86 feet above datum at spring tides. This would be equal to a flow of 28 feet at spring tides at the Gat channel. An average of three months' observations gave the following results:—

Name of River.	Extent of Tidal Influence, and remarks.	Rate of Fall per Mile.
	Miles.	Feet.
Ouze . .	40, back-water abundant. . . .	0·63
Nene . .	35, back-water rapid in winter only	0·73
Welland .	15, very little back-water . . .	1·50
Witham .	5, approaching Nene in back-water	1·97
Ditto . .	Might be 35	Might be equal to Nene.
Ditto . .	From and below Hobhole in a length of 3 miles	2·80

Mr. Joseph Taylor remarked that the Grand Sluice had been built across the head of a tidal and navigable river, but during the greater part of the year there was no ingress or egress of water through that sluice; he was, therefore, not surprised to hear that the channel had been silted up to a depth of 7 feet or 8 feet below it. Moreover, the silt could not be removed until the doors of the sluice were opened, and the doors could not be opened until the silt was removed; consequently the silt was stirred up with poles, and in time it got away. But if any sudden flood occurred while the sluice remained closed, it would probably lay the country above the sluice under water. The effect upon the navigation was ruinous, and he imagined the drainage interests were not much better served. As the sluice was inoperative for the greater part of the year, there must be a great deposit of silt. If it were taken away, the silt removed by dredging, and the bed of the river

lowered as much as it would admit of, he saw no reason why the condition of the river for navigable purposes should not be much improved, and at the same time a freer course be left for the drainage waters; and looking to the interests at stake, as affecting the port of Boston, he thought it was a matter which called for immediate attention.

Mr. Redman observed that Boston Sluice was built under no less an authority than Smeaton. Smeaton, Langley Edwards, and Grundy reported upon Boston Harbour in the year 1761. The arguments of Smeaton, at that time in favour of the erection of the sluice, were of a similar character to those made use of at the present day in favour of its retention. It was stated plainly that the primary object of the sluice was to keep out the tidal water; the natural consequence was the deterioration of the town of Boston as a commercial port. It was manifest that great changes below Boston must have occurred, when it was recollected that at no very remote period of the history of this country Boston rivalled the metropolis in its shipping trade, and that, as recently as the year 1720, vessels of from 250 tons to 300 tons could discharge at the quays. Undoubtedly many of the sluices in the Fens had been to a considerable extent influenced not only in design but in circumstances by the works carried out by the early projectors; and the design of Vermuyden was to lead the water to the best possible outfall for the landed interests of the district alone, and to exclude the tide, and this had been followed by many of his successors. It was to be borne in mind that the late Mr. Rennie proposed a sluice across the Nene below Wisbeach. He did not think the decadence of ancient Italian ports upon a tideless sea bore any analogy to the decadence of British ports where the tidal range was large. Thus, in Boston Deeps, the range of spring tides was from 20 feet to 25 feet, while there was a depth of only 12 feet of water at the sluice: either the sluice must exercise an injurious influence upon the Estuary, or the tortuous and difficult character of the Estuary itself had led to these results. There were harbours not far distant from Lynn, as, for example, Wells and Brancaster, which had been kept open by the natural agency of the tide alone. Rye Harbour, on the Sussex coast, was an instance analogous to Boston; and there also the same Engineer recommended a like expedient with similar results. That harbour was undoubtedly sacrificed to the landed interest. The tide was excluded by the Scott's Float Sluice, which was blown up about the same period as the Denver Sluice. The erection of the sluice caused some commotion at the time; and although attempts were made to prevent its re-erection, and even to destroy the works as they proceeded, it was rebuilt, and had stood to the present day. A large area of valuable land was reclaimed, but the harbour suffered greatly. Smeaton indorsed

that work, and himself designed certain works in connection with it.

The Author of the Paper referred, in support of his proposal, to the unobstructed outlets of the Ouze, the Nene, and the Welland. Reference had also been made to the Denver Sluice; but that was not a parallel case to the Boston Sluice, as it was 7 miles up the River Ouze. The early decadence of Lynn Harbour had been by some attributed to the Denver Sluice: when that was blown up there was the same desire, as had been mentioned in the case of Rye, to prevent its reconstruction; and there were reports at the time by Mr. Walker and Mr. Mylne upon the effects which they alleged would take place from the removal of Denver Sluice, and developing the tidal range above. Mr. Redman could not quite agree with the deductions drawn by Mr. Murray from the facts he had brought forward with regard to the destruction of Denver Sluice; for though when in ruins the tide possibly did not pass above, had the sluice works been entirely removed, and the river developed above, the results would have been very different. The early decadence of the port of Lynn had, to a certain extent, been forgotten, owing to the recent modern improvements of its river. The Ouze (Eau Brink) Cut, conjoined with the new lower cut to the north of and below the town into the Wash, had so improved the river that the effect of the Denver Sluice on its early condition was, to a certain extent, forgotten.

Mr. Hawkshaw, Past-President, said, he had reported on several occasions in 1861, 1862, and 1864, on questions of importance to the district; but he had found it impossible to induce the various parties interested in separate objects to act in concert for carrying out a comprehensive scheme of improvement. There was no difficulty in greatly improving the harbour of Boston, provided the wealth and commerce of the place were sufficient to justify the necessary expenditure, and provided the money was found for doing it. Boston was formerly a good harbour. It was now very bad, and was getting worse every year. As to the suggested measures for its improvement, he was surprised to hear it argued that it would do no good to remove the Grand Sluice. Consider, for a moment, what would be the effect on the port of Liverpool of constructing an embankment across the Mersey, just above the docks, and putting in a sluice there, and then a pretty accurate opinion could be formed of what had been the effect of the Grand Sluice at Boston. It was not the quantity of fresh water only that had to be taken into account—indeed the volume of fresh water in the Mersey was small; but he believed, if the sea were admitted 20 miles or 30 miles above Boston, it would necessarily tend to improve the harbour. Other questions had, however, to be regarded. The land-owners on the River Witham wanted fresh water for their cattle,

and not salt water, and they objected to salt water flowing up into the country. That was a local difficulty. Then, again, to remove the Grand Sluice and to carry out the works proposed, whether the cut were taken to Clayhole or to the Maccaroni channel, the cost would amount to £100,000, and there was no such sum available. Mr. Frow's estimate of £30,000 was altogether inadequate. He had quite lately, at the instance of those gentlemen who first consulted him, carried out the minor scheme included in his report. As they could no longer suffer their lands to be overflowed, he had built a sluice across the river into which they drained, and had erected powerful pumping-engines which lifted the water at the sluice 5 feet, and gave an artificial fall to that extent. These gentlemen could not be expected to have their property ruined, because they could not induce people to combine together for the improvement of the Boston navigation. In like manner he had advised that the river Witham should be deepened and widened above the Grand Sluice; and that work, which was good as far as it went, was now being carried out; and if all those interested could be induced to combine together at some future time, perhaps it might be decided to take away the Grand Sluice, and carry out the further works for improving the harbour of Boston, and with which the improvements at present in progress on the Witham would be in nowise inconsistent.

Mr. W. Shelford thought that the construction of the Grand Sluice was a mistake in principle, which could hardly be justified in practice. He was for some time in local charge of the works on the Nene for Mr. Fowler. In 1856 a dam, similar to the Boston Sluice, was constructed in the tideway of the Nene, 3 miles from Wisbeach and about 14 miles from the sea. Passages were left for the fresh water, and there were slackers on the up-stream side to dam back the inland water for navigation and irrigation. Two years and a half after the dam was completed, the river had silted up to a considerable extent for some miles downwards, and the port of Wisbeach was damaged. The remonstrances of the inhabitants against this being of no avail, a mob attacked the dam and destroyed it in one night; and he was himself roughly handled in attempting to defend it. After the dam was destroyed, the effect was very remarkable; whereas, before its destruction, there was a gradually increasing quantity of silt on the up-stream side of all obstructions in the river: three days after its removal, he observed that the deposit was being rapidly removed from the up-stream to the down-stream side, showing that the removal of the dam had restored to the ebb tide its preponderance of power over that of the flood; from which it would appear, that if it was desired to keep a river of that class open by tidal scour, the free oscillation of the tidal wave must not be interfered with.

It seemed to be thought by Mr. Murray that the Grand Sluice ought to be retained, and that if it were removed it would not effect any improvement, because there was a want of fresh water in the Witham. But he thought the question of the comparative value of tidal and fresh water was involved in this, and that the want of fresh water might even have justified the erection of the Grand Sluice. In such rivers the tide came in largely charged with silt, which was deposited in time of drought at the head of the tidal influence where the ebb tide was then weak. That went on from day to day until a freshet came down from the uplands and carried the silt into the tidal reservoir, whence it was scoured out to sea. He believed the navigation of the Nene, the Ouze, and the Welland might be made superior to the Witham, if there was no fresh-water reservoir at its head. He thought the point at which the introduction of fresh water was most advantageous was at the head of the tidal influence, and that it gradually diminished from that point to the outfall, where it was of no value.

The difficulty of reconciling the conflicting land and drainage interests of the district had been referred to by Mr. Hawkshaw. So far as the engineer was concerned, he thought the case might be, and had been, met in this way; the full flow of the tide might be admitted, the effect of which would be favourable to the navigation, and the low-water line might be lowered, thus giving a natural outfall for the drains. The irrigation interests would be provided for by constructing a canal or drain from the upper portion of the river, so as to bring the fresh water down in a smaller channel through the district to be irrigated, giving it an outfall into the original river, at some lower point.

Mr. Brunlees considered, from his knowledge of the Witham, and from his experience in dealing with other sandy estuaries and rivers, that the Grand Sluice was a drawback to the district, because so long as the flux and reflux of the tides and their scouring influences were retarded, the deposit of silt in the haven below the sluice must increase; thereby limiting the navigation to vessels of small draught, and preventing the free discharge of the land water, and a sufficiently low level for the drains of the large district which had the Witham for its outfall.

It had been proposed to divert the outfall of the Witham through Clay Point to Clayhole. This would no doubt improve that river, but the Welland, diminished in volume, would be left to struggle through a long run of sands, and would be liable to be gradually silted up. He therefore contended that the Witham and the Welland should be united at as high a point as possible, much as nature had indicated by their present position, and that when these streams were fixed and trained their united powers would maintain a good outlet.

Notwithstanding the Author had shown an intimate knowledge of the subject, and his suggestions for the improvement and outfall were thoroughly practical, there was still a large question untouched—the reclamation of the land which should follow on the fixing of the channels, and he thought it would be well if the present Paper were supplemented by another on the reclamations in the Estuary.

Mr. Hawksley, Vice-President, said, he would take the opportunity of suggesting what appeared to him to be the change of circumstances under which it might now become desirable to remove the Grand Sluice at Boston. There was no doubt, that, at the time the Grand Sluice was first erected, it was the proper thing for an engineer to do, because the landed interests, and particularly so of that neighbourhood, were then much more important than the commercial interests. Nevertheless, it must be confessed, that the result was highly detrimental to the port of Boston. The effect had been to cause a considerable silting up of the harbour of Boston, and of the channel leading to it; and there could be no doubt that if the Grand Sluice were removed, and if the tide had a free run up the river to Bardney Lock, Boston Deeps, the harbour of Boston, and a large portion of the Witham itself, would be much deepened, and vessels would be able to come up to Boston of a size which now could not approach that port. But many difficulties would present themselves in carrying out an undertaking based upon that idea, which did not appear to have been fully anticipated in the Paper which had been read. It must be borne in mind how essential it was to keep the salt water out of the Fens; for not only was it necessary to remove the excess of fresh water—which consisted of rain falling both on the Fens themselves and flowing from the higher lands which descending to the Fens, and caught by the catchwaters, was by them ultimately delivered into the fen drains and passed to the sea outfalls—but it frequently happened that the rainfall in the Fens was below the amount of the summer evaporation; and that, consequently, the Fens required to be fed by the admission of other fresh water obtained from the river, in order to maintain the level of what was locally called the 'Sock;' and that if that fresh water were not admitted, vegetation would suffer, and it would become impossible to maintain the cattle in the fields. A considerable difficulty would obviously arise in maintaining this supply of fresh water if the river Witham were to be again converted into a salt-water channel.

At the time the river Witham was changed from a salt-water channel to a fresh-water channel, the alteration was effected with the view of supplying the Fens with fresh water for the purposes of vegetation and of the breeding and feeding of cattle, as well as to

facilitate a system of communication by internal navigation instead of by roads which then scarcely existed; and up to the present time, undoubtedly, the effect of the engineering of that day had, in these respects, been perfectly successful. He did mean to say that, by such a change, if it should be considered essential—and possibly it might now be considered essential — the ports on the east coast in which the tides were now dammed back by sluices could be improved for commercial purposes to the general benefit of the country at large. This, however, would not be accomplished without many accessory engineering works needing to be established to prevent the serious injuries to other interests to which he had alluded. It was quite clear, if salt water were admitted up the river Witham, that it would be necessary, not only to maintain special sluices upon all the side drains which were now connected with that river, so as to exclude the salt water as far as possible; but it would also be necessary to bring down a supply of fresh water from the upland country at a point above that to which the salt water of the tide could possibly reach in the dryest periods. That would be a work of considerable difficulty, not perhaps in an engineering sense, but in consequence of the small quantity of water which was to be found in the upper part of those rivers. The stream in the river Witham above Bardney Lock was in a dry season scarcely worthy of being called a river at all; and the Fens, on the wetness of which so much was said on a former occasion, were at this moment being mainly fed by the water which had been gathered in the early part of the spring. Therefore, the simple engineering works, which were suggested as being consequent upon the removal of the Grand Sluice, would not alone be sufficient for the prevention of great damage during years of serious drought—such years, for instance, as 1864, and during a portion of the summer of 1868, and on some other occasions, when indeed the rainfall of the whole year had been reduced to as little as 16 inches—a fact which would no doubt appear surprising to many engineers, whose experience had lain on the west side of the kingdom, but which was perfectly well known to those engineers who had become practically acquainted with the fen districts of the east coast.

Then, with regard to the important question which arose respecting the relative level of the land and the sea in the present age, and in former, and perhaps in future ages, he was perfectly satisfied himself, and he thought philosophers of the present day had come very generally to the same conclusion, that the whole of this country, in common with a large portion of Europe, was being slowly but gradually tilted; and that the effect of the tilting was that for the most part England was gradually descending, and more particularly on the east coast. On the other hand, there

could be no question that the eastern part of Europe, from the Baltic far into the interior of Russia, was all slowly ascending. If that were the fact, and he firmly believed it to be so, and geological examinations of recent date tended to that conclusion, it would suffice to explain the many anomalies which had been stated to exist in the course of this discussion.

Mr. Abernethy remarked that, for some years past the drainage of the district had been deteriorated, mainly because the outlet of the river Witham had silted up, and unfortunately there had not been sufficient accord between the parties interested in the navigation and drainage to enable the latter to have due consideration. About three years ago he found, opposite Hobhole Sluice, a considerable shoal, several feet above the level of the sill; this affected the whole of the drainage, and at that time a Bill was brought into Parliament to empower the erection of a pumping station near the eastern marsh to transfer the drainage from the upper to the lower fen district. If the present system were continued, the lower fen district, having no sufficient outlet, must become deteriorated to a great extent. If, as had been proposed, the river Witham was deepened at the Scalp, and the channel at Hobhole Sluice improved, by excavating the bed to the level of the sill, so that a thorough outlet would be made into the river, there would be no occasion to drain the upland district at the expense of the lower. Unless there was complete accord between the parties interested in the navigation and drainage as to deepening the main outlet of the river, he was confident the whole of the drainage would gradually deteriorate from year to year.

Mr. T. Marr Johnson said, with regard to the straight outfall proposed by Mr. Frow, with a view of joining on with the Ouze outfall, it seemed to him that there would be no present advantage to be gained by such a plan. It could not be effected, except at enormous cost, until the reclamation of the sands adjoining had been much advanced, and the chance of reclaiming these was very remote. He believed the Wash had only been diminished by about one-fourth of its area since the time of the Romans; at that rate, it would be several hundred years before the existing sands were so far enclosed that the outfalls could be economically brought together. He thought there were disadvantages in attempting to combine the two channels, inasmuch as by so doing the errors attributed to Vermuyden would be repeated,—not giving separate outfalls to the districts into which the Fens were divided, thus inducing perpetual quarrels amongst the drainage interests. He presumed that the main object now was to improve the outfall of the Witham; but, inasmuch as the distance to sea by Mr. Frow's proposal would not be sensibly diminished, the inclination of the bed would remain practically as it was at present. The mainte-

nance of the training banks across the sands east of the Maccaroni Channel would be very costly, and there would be a most awkward junction with the Welland.

Taking into consideration the difficulty in getting funds for the improvement of the Witham outfall, he could not help regretting that something had not been done to aid the Lincolnshire Estuary Company, in their proposal to reclaim large tracts of salt marsh on the left of Boston Deeps. This Company, like the Norfolk Estuary Company, was saddled with an Act of Parliament which, although invaluable to the drainage interests, was not of much use to the shareholders, on account of the heavy obligations attached to it. In the first place, before an acre of this marsh could be reclaimed, a new outfall had to be made for the Witham, and another for the Welland. Then the new outfalls had to be maintained, by the removal of the existing shoals, and by the clearing away of any others that the works might cause. The Company had also to pay for Admiralty inspections, together with the cost of surveys to be made to find out the obstructions caused by their works; and to enclose nearly the whole of the existing salt marshes included within their limits free of expense. Another large breadth near the sea was to be enclosed at cost price. Further than this, roads 30 feet wide had to be constructed, and all these things had to be done before an acre of land became the property of the Company. Hampered with such onerous conditions, it was impossible that the Company could proceed with the project. But if the drainage interests had combined, and had given proper aid, either by taking up a proportion of the shares or by granting subscriptions adequate to the benefits to be received, there was no question that the two interests would have reaped incalculable advantage, by the improvement of the outfalls and of the drainage and navigation up to Lincoln.

He was curious to know why slopes of 4 to 1 had been selected for the proposed outfall cut. It was the same slope as that prescribed for the Norfolk Estuary Marsh Cut; but although an attempt was made to form that cut at slopes of $4\frac{1}{2}$ to 1, and of 4 to 1, those slopes could not be maintained. In the cases of the Ouze, the Nene, and the Witham, the slopes varied from $1\frac{1}{2}$ to 1 to 3 to 1. The Eau Brink Cut was 3 to 1. The Witham, where unprotected, was $2\frac{1}{2}$ to 1; where protected with fascines, about $1\frac{1}{2}$ to 1.

He took some tidal observations in the Witham, for Mr. Fowler, six years or seven years ago, and found that high water rose 8 inches higher at the Grand Sluice than at the outfall. There was no rise to compare with that in the Ouze or in the Nene, where no sluices obstructed the tide. It would be interesting if the Author would state whether this same rise of 8 inches existed under the altered

condition of things; viz., the shoaling of the river, near the Grand Sluice, as described in the Paper. With regard to the removal of the Grand Sluice, so much had been said on that subject, that very little remained to be added. He thought that no efficient natural drainage could be completed while that sluice remained. He did not apprehend any difficulty with regard to the fresh-water supply; neither did he believe there was a great deficiency of water in the upland district. The obstructions to the free discharge of water into the Witham at Lincoln were so great, that the lands above were constantly inundated, and the drainage was most imperfect at all times, and much of the water was diverted or wasted. He knew of one instance in particular, in the Western district, where an outlet of 16 feet was provided for in the Act. This was construed to mean 16 feet area, and the consequence was the drainage of the whole district of 5,000 acres or 6,000 acres was dammed back, until the water of the lower districts had passed off. If the waters of this and the adjoining districts were properly regulated, there would be a good supply of fresh water down the Witham in times of drought: and he did not see any difficulty in preserving at least the same quantity of fresh water as there was at present. The principle upon which this supply might be preserved, in case the tide were allowed to flow freely, might be thus described:—A side cut might be constructed from the head of the tidal navigation upwards which should be the means of maintaining the navigation, and which would also be a fresh-water channel and reservoir. From this channel, or reservoir, fresh water would be distributed by drains, and occasional syphons, into the local drains. It was merely a question of size of reservoir, and therefore quite easy to maintain as large a supply as the watershed yielded. The local drains should be of much larger capacity, both for the sake of holding the fresh water during the time of high water, to be discharged at low water, and for containing the fresh water for the supply of the districts during droughts. He thought this storage of water was somewhat lost sight of in drainage matters. He did not consider it was more difficult with this river than with others. No doubt the want of unanimity of interests was the great difficulty in the present case. Landowners in the Fens were mostly enterprising and pushing, and when it was found impossible to accomplish drainage operations by combination, engines were erected even at the risk of drowning the lands of less enterprising neighbours; and having once established engines, it was not surprising that there should arise an indifference about combination, which, however much it was desired in the first instance, could only then be a source of unnecessary expense. Hence combination became daily more difficult. He did not see any other difficulty in so improving

the Witham, that the tide would flow up to Lincoln. The tide in the Ouze flowed 37½ miles; and the distance from the mouth of the Witham to Lincoln was only 41 miles. He hoped before the occurrence of some great catastrophe by the bursting of banks, a useful combination would be brought about, and that these works would be carried out upon a comprehensive plan, for the benefit alike of the navigation and of the whole area of valuable land now so imperfectly drained by the Witham.

Mr. Wheeler observed, in reply, that the discussion had related principally to the erection of the Grand Sluice and its effect. He had mentioned in the Paper that the Witham was a river 68 miles in length, draining a tract of country of nearly 700,000 acres of land; and that across this river, at a distance of 8 miles from its mouth and within about one-third of the distance of the natural run of the tidal wave, the Sluice had been erected. This Sluice was a construction so arranged with self-acting doors, that while allowing the fresh water to flow through, it completely barred the progress of the tide. The result was that the flood tide, which passed over extensive beds of shifting sands, entered the confined part of the river charged with a large amount of mud held in suspension, and flowing up at the rate of about 4 miles an hour, was suddenly stopped in its course by this sluice. In two hours the tide had reached its height, and then gradually settled down again. In summer, when there was little water passing off the land, and consequently no stream of fresh water down the river, the tidal water for a time remained almost stationary, and retired very gradually. There was no back current of any force, and the heavy particles of silt and sand brought up in suspension had time to settle by their own gravity on the bed of the river. The deposit which thus accumulated varied according to the state of the summer, from a depth of 3 feet up to, in a very dry summer like that of 1868, 10 feet or 11 feet, in fact to such a depth as to shut out the neap tides altogether; and this remained until the winter, when the upland waters came down in sufficient quantities to scour it out again, and remove it to the Estuary. In a very wet winter, followed by a wet spring, such as 1866-67, the river would be scoured out down to its natural bed; but in ordinary seasons a great part of the deposit remained. (Plate 8, Section.) The effect of this deposit, both on the drainage and also on the navigation of the port, was most serious. He ascribed it entirely to the erection of this sluice, and he might say, that the time which had been occupied in discussing this point had by no means been thrown away, because, if he was correct, the example of this river might act as a warning to engineers who had rivers to deal with under similar circumstances. Had the effect of this sluice on the Witham been more generally known, it was possible that the attempt to

place a similar dam across the Nene, above Wisbeach, would never have been made, and the cost of the works would have been saved to the Commissioners. On the other hand, if the inference drawn from this discussion were that a sluice so placed was beneficial in its operation, then an example had been given which could be repeated in other situations. But he thought that the weight of evidence, and the tendency of the remarks, not only of those who had taken part in the discussion, but of all the Engineers, without exception, who had specially considered the matter, when called in to report on the drainage and navigation of the district, was decidedly against the sluice. Mr. Rennie, Mr. Telford, Sir John Rennie, and, more recently, Mr. Hawkshaw, had, one and all, pronounced the sluice to be a great mistake. Such being the case, the question had been asked, why was this sluice ever erected? and why was it now allowed to remain? To answer the first part of this question, it was necessary to go back at least two hundred years, when the attempt was first made, by the Duke of Bedford and the other adventurers, to reclaim the great Bedford Level. They employed, as their engineer, Vermuyden, who came from Holland, where large works of reclamation had been already carried out, but on lands lying contiguous to the sea itself, and not having natural rivers passing through them. Under such circumstances the only practicable course to pursue was the one adopted,—to make artificial cuts and protect them at the end by sluices. Unfortunately, Vermuyden failed to perceive the difference in the circumstances of the country he had left and that to which he had come. The Fens of the great Bedford Level were intersected by large natural rivers, which formed the main channels for carrying off the drainage waters. The obvious course that ought to have been pursued, would have been, first, to have attended to these outfalls, by embanking their sides and straightening their course, and then leading the fen waters into them by such new cuts and drains as might be necessary. Instead of doing this, and aiding and improving the works of nature, Vermuyden ignored the rivers and made long straight cuts. These being made through the porous soil, and for want of a continual current, soon filled up; and then other cuts and fresh drains were made, and unnecessary works executed at great cost and loss to the adventurers, who found, after spending enormous sums of money, that they were in little better position than at starting. Doubts were entertained at the time as to the effect of this system of internal drainage, and Westerdyke, another Dutch engineer, was sent for by some of the adventurers who felt dissatisfied. He at once condemned Vermuyden's plan; but in spite of this it was still persisted in, which could only be accounted for by the jealousy which had ever existed between two sets of Commissioners, who ought, on every consideration, to have

acted in concert. The adventurers of the Bedford Level saw that, by improving the outfall of the rivers, they would be giving material assistance to the Port of Lynn, and rather than do this they tried every imaginable plan to make their own works effective without touching the outfall. At length the conclusion forced itself unwillingly upon them that this was an impossibility. Their proceedings were analogous to those of a farmer who, having a field of very wet land on his farm, should proceed to drain it with tiles, without providing an outfall, by scouring and cleaning out the ditches; and then, when he found his drainage ineffectual, should keep on adding more drains, while the ditch into which they were to empty could not discharge the water brought into it, owing to its neglected and foul condition. It was not until every other plan had been tried that, at last, those extensive works for the improvement of the outfall—the Eau Brink Cut and the new channel below Lynn—were commenced, the carrying out of which had such a beneficial effect on the whole drainage of that portion of the Fens, and by which 280,000 acres of land had been benefited, but at a cost of £600,000.

The unfortunate example set by Vermuyden was followed up in the other districts, and it was only with great reluctance, and after large sums of money had been wasted in abortive attempts, that the Drainage Commissioners finally found themselves compelled to improve the outfall of the Nene below Wisbeach, and the Welland from Spalding down to its outfall. On these three rivers the Commissioners of Drainage had then found, notwithstanding the use of steam power, and every other plan, that the rivers which nature had provided were the natural outfall for their water, and that no drainage operations could be effective, unless these were put in the best possible condition to allow of the passage of the water; and that although, in improving these rivers, they might be serving other interests than their own, yet after all it was their best policy, in fact, their only alternative. Here, then, was the secret of the difficulty the engineer had always presented to him in dealing with matters of fen drainage, and led to the necessity for that caution in giving an opinion which Mr. Hawkshaw had been obliged to use in drawing up his reports on the Witham. The question asked of the engineer was not what was the best plan to pursue, but what plan could be devised that could be carried out, independent of all other interests, which should effect that object without benefiting the neighbours. It was this feeling that had assisted materially in retaining the Grand Sluice in its situation, and had caused the rejection of every plan that had been suggested to the Witham Commissioners by all their engineers for the improvement of the outfall. Mr. Rennie tried every argument in his power to induce the Commissioners to commence their works

of improvement on the lower part of the river, and there was scarcely a report of his on the Fens extant in which reference was not made to this subject: but hitherto all such advice had remained unheeded, and the Commissioners declined spending any money out of their own dominions. No doubt the Drainage Commissioners, by the removal of this sluice, would materially improve the navigation to the port of Boston, and so benefit the town; but, after all, by so doing they would be really benefiting themselves. Boston was entirely an agricultural town. It existed solely as a mart, where the produce of the country round was brought to be exchanged for articles of merchandise required by the growers of corn and meat. It had no extraneous manufactures; the few large establishments that existed were entirely for the supply of the wants of the farmer, such as oil-cake manufacturers and agricultural implement makers. The more cheaply the transit of merchandise could be effected between the town and country, and the town and the rest of England, the more profitable must it be to the farmer. For instance, the cost of sending corn by rail to the places to which Boston merchants chiefly consigned it was about three shillings per quarter; whereas it could be sent by ship for one shilling. Owing to the state of the river in the summer of 1868, ships could not be got up to the granaries, and the corn was obliged to be sent by rail; and this loss of two shillings, being the difference in the cost of transit, must fall on the farmer. So with coals, and the ordinary articles of daily use and luxury. Attempts had been made to run a regular service of steamers between London and Boston, whereby all heavy goods could be imported at much less cost, but the state of the river prevented it. A firm in the north had built a screw-steamer on purpose for the Boston trade, but after using it one season, owing to the state of the river, it was obliged to be withdrawn. Large quantities of foreign oil-cake were imported from the Baltic and Marseilles, and of linseed from Italy and Odessa. When the river was in order the ships could come up to the merchants' warehouses and discharge their cargoes. Now every cargo of cake had to be brought up in barges at a cost of £40 to £50, which compelled the merchant to sell the cake at a higher price to reimburse himself. It was clear, then, that the interest of the port and of the Drainage Commissioners in this case were one; and that the removal of this sluice would add to the general prosperity of the district.

There was one other reason to which he had not yet alluded, why this sluice should originally have been erected? At that time the only means of transit for merchandise and produce into and out of the Fens was by sea and by the inland rivers. In erecting this sluice it virtually made the Witham a canal, and

facilitated the passage of barges and other boats to all places between Boston and Lincoln, and thence by the Fosdyke and Trent to all the midland parts of England. But this could remain no longer as an argument in its favour, as the railway had almost entirely superseded the Witham as a means of transport for the inland towns, and the navigation had become quite a secondary consideration.

The banks had only recently been both heightened and strengthened, and were above the reach of the highest spring tides. And if there were the least apprehension of danger from extraordinarily high tides, the plan could be tried of leaving the doors of the sluice open to all ordinary tides, and closing them against the highest of the spring tides, which would no doubt give sufficient back scour to keep the river free from deposit.

As to the objection that the salt water would impregnate the land on either side of the river and injure the cultivation of the crops, he might say that there were numerous examples of tidal rivers passing through similar strata which did not in the least suffer from any such ill effects, and it was only necessary to point to the lands below the Sluice and bordering on the Wash and the other tidal rivers to dispel the idea. To another objection, that it would injure the wells and deprive the residents of their supply of fresh water, no doubt there would be some inconvenience from this; but the residents on this river would then be in no worse condition than those on other tidal rivers: besides, owing to the leakage of the salt water through the doors, not only on the Witham but on all the other main drains in the Fens, the water in the summer for several miles above the outlet became so brackish as to be unfit for use.

A more serious objection had been urged, as to the deposit that would be left by the tide at the extreme end of the tidal wave. This no doubt was a matter for consideration, but yet the effect produced by this was only slight and temporary compared with the deposit which now took place; and the first run of fresh water down the river would remove it, while such deposit as did take place would be so high up the river as not in any way to interfere with the navigation. On the Welland this deposit, at 13 miles up the river, had been only 2 feet 6 inches thick, as compared with 11 feet in the Witham. On the Ouze, about 30 miles up the 100-feet river, and 18 miles above Lynn, the deposit reached sometimes as much as 4 feet in thickness; but it rapidly disappeared, and in all these cases it might be reduced almost to nothing by continuing the training of the river still further through the sands into deeper water.

Finally, the strongest argument in favour of his view of the subject was the fact that, with regard to these four rivers draining large tracts of fen lands, one had a sluice across it, and a river full of

deposit stopping both the drainage and navigation; the three other rivers had no sluices and had no such deposit, the navigation was unimpeded and the drainage was much better than on the Witham. For although, as had been remarked, there was a sluice on the Ouze, it had been explained that this bore no resemblance to the Grand Sluice, being situated 10 miles above Lynn, and the tides having an uninterrupted course up the 100-feet river. Denver Sluice had had a most injurious effect on the Ouze, and had been a subject of controversy ever since it was built. He did not wish it to be supposed that he considered sluices in all situations a mistake, quite the contrary. At the end of all artificial cuts emptying into tidal rivers, or arms of the sea, sluices were absolutely necessary, to prevent that silting up which would take place from the want of fresh water to remove the deposit at the end of the tidal wave, and which would therefore increase year by year until the whole channel was silted up. Where, too, a river debouched into an arm of the sea, or into deep water, the erection of a sluice might be the means of saving many miles of embankment, and as, in such a situation, there would be no danger of deposit, there could be no objection. Again, where for the purposes of canal navigation a sluice or staunch had to be erected across a stream, to change a river into a canal, if this were done where the current was only downwards, and the obstruction was beyond the reach of the tidal wave, the objection no longer held good. But these were all different situations to the sluice in question, which was so placed as to interfere with the natural flux and reflux of the tide, and which, if its channel were only properly regulated, would always have a beneficial influence in scouring and cleansing and keeping it free from deposit; and every effort ought therefore to be directed to increase the length and duration of the tidal wave, and so to add to its force and scouring power.

One other point in the Paper had attracted attention, the best method to be adopted for training the outfall of the Witham and the other fen rivers into deep water. Mr. Murray had referred to the Norfolk Estuary and the other schemes for reclaiming portions of the Wash, and had expressed the opinion, that these schemes must prove unsuccessful if carried out. But he differed from that opinion. The Wash was rapidly and visibly silting up. He could state, from his own personal knowledge, that the whole of the foreshore was rapidly encroaching on the water, low water line being now in some places from 2 miles to 3 miles distant from the old Roman banks, and there were numerous 'intakes' all along the coast, showing the extent to which the land had warped up. The sands also in the middle of the Wash, called the Long Sand, the Roger, and the Bar Sand, if rightly drawn on the Admiralty chart and the Ordnance maps, which were made from surveys forty or

fifty years ago, were also increasing in height and extent. Where on these charts a large space was shown between these sands, with depths of water sufficient for a boat to pass through, all was now filled up and the sands almost joined. This silting up he attributed to the alluvium washed away from the east coast, and brought by the tide into the bay; it was a matter meriting the greatest attention as affecting the efficiency of the outfall of the rivers which debouched into the Wash, rendering their training a never-ceasing work. The training completed at great expense at one time might put the drainage in a thoroughly effective condition, but in twenty years' time perhaps, owing to this silting up of the Estuary, the outfall would again become defective and again require pushing forward into deep water. Most comprehensive schemes had from time to time been brought forward for taking advantage of this accreting process, which if they had been carried out, the greater part of what was now sands and water would have become valuable land. The first was that of Kinderley, who proposed to warp up the whole of the bay. In 1839 Sir John Rennie brought out a scheme for training the four great rivers into one outfall and reclaiming 900,000 acres of land at a cost of £3,000,000; and as he estimated the value of the land when fit for enclosure at £6,000,000, this plan would have redeemed from waste a tract of land as large as a county, to the great profit of those who carried it out. The scheme was mainly taken up at the time by Lord Hardwicke, who was then, he believed, Chairman of the Bedford Level Commissioners, and other large landed proprietors, and several meetings were held in London; but the difficulty of procuring the necessary capital at the time, which was one of panic in the money market, prevented its further prosecution. He had no doubt that if the system of training these rivers with fascine work, pushing them on gradually into Lynn Well, were pursued, the land on either side would rapidly accrete; and if Sir John Rennie's plan had been carried out, it would long before this have been quite fit for embanking, and worth £50 an acre at the least.

In 1851, another scheme of a less extensive character was brought out, with Sir John Rennie and Mr. Freebody as Engineers, termed the Lincolnshire Estuary Company, for training and uniting the rivers Witham and Welland, and enclosing 30,000 acres of land. An Act of Parliament was obtained, but difficulties arising from sufficient powers not having been taken to settle the claims of the frontagers and others, the powers of the Act had been allowed to drop.

Now, if any comprehensive plan of this kind could be carried out, he thought there was no doubt that Lynn Deeps was the proper outfall for the waters of the Witham; but in default of this, to attempt to train that river through the beds of shifting sands

that intervened between its present outfall and Lynn, would require an expenditure of money that no benefit that could ever ensue would justify the parties interested in that river in incurring. With regard to the plan referred to by Mr. Frow, who proposed to do all this training for £30,000, he considered that that sum would hardly be sufficient to pay the preliminary expenses, and he thought when it was considered that to carry it out the river would have to be trained through 5 miles or 6 miles of shifting sands, and have to run directly across the tidal current coming up Boston Deeps, a most difficult and hazardous undertaking under any circumstances, every one at all acquainted with such work would fully endorse this opinion. Failing any comprehensive scheme, therefore, the obvious place for the outfall of the Witham was into Boston Deeps, and the place which had hitherto found favour, and which had been recommended by Mr. Hawkshaw, had been by making a direct cut across the Clay Scalp into a place called Clayhole. The advantages of this plan would be very great; the objections,—the cost and the separation of the Witham from the Welland, unless the managers of that river would continue their training to rejoin the Witham which they had not the funds to do. Another alternative, alluded to by Mr. Brunlees, appeared likely to answer every purpose, and it could be effected at a fourth of the cost, by following the present course of the water, but confining it to one channel, by continuing the fascine work from its present termination to a point 2 miles lower down to the confluence of the two rivers. The fall of the water at present between these two points was from 2 feet to 3 feet per mile, owing to the water continually varying its channel amongst the sands; but by the training, these sands could be fixed, and in time become capable of cultivation, and the fall would then be reduced to what it was in the other rivers—from 6 inches to 8 inches per mile—or a lowering of the water in flood times at the sluices of from 3 feet to 4 feet, or more than the difference between the flooding of the fen lands, or their effective drainage. It would cause the waters also to discharge at once into a channel with a clay bottom, and so remedy, to a great extent, the evil now caused by the silt being carried up the river. For the bottom along the whole of Boston Deeps, at any rate the upper part, was clay. And it would possess this further advantage, that if ever any more comprehensive scheme were carried out, the river would not have been diverted from its natural course, but the work now proposed would only require further extension.

Boston Deeps was nearly as good a channel for discharging the waters as Lynn Deeps, there being very little difference between the time of ebb and flood in either channel. He understood Mr. Murray to say, that the tide set into Lynn Deeps and then passed towards the north over the sands into Boston Deeps. But in point

of fact the time of flood tide in Lynn and Boston Deeps was almost coincident. A vessel lying in Boston Deeps would swing round about the same time as the Lynn Light Ship, occasionally varying with the state of the wind. The tide in Lynn Well would be a little before that in Boston Deeps; but the utmost advantage in favour of the former would be from a quarter of an hour to twenty minutes. He stated this not only from his own recent observation, but from conversation with the pilots of the port. Possibly it might have been different some years ago, before the sands reached their present extent, because now at nearly high water there certainly was a set of tide from the west towards the main on the north side of the Deeps; but at present, although it was true there was a bar at the exit of Boston Deeps, yet the flow of tide into Lynn Well had little or no advantage in time.

December 8, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The discussion upon the Paper, No. 1,147 "Description of the River Witham," occupied the whole evening, to the exclusion of any other subject.

December 15, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,211.—"On Machines employed in Working and Breaking-down Coal, so as to avoid the Use of Gunpowder."[1] By SAMUEL PARKER BIDDER, Jun., Assoc. Inst. C.E.

THE object of this Paper is to direct attention to the 'winning' of coal by mechanical appliances, with the view of obviating the loss in production and the danger to the colliers which are incidental to the use of gunpowder.

The special system to be described is brought before the Institution after having been submitted to actual trial on a working scale at the Harecastle Colliery, where the results were so satisfactory as to induce the proprietors to make arrangements for its immediate adoption.

The importance of discovering some efficient substitute for gunpowder in coal-mining is generally admitted by practical men; and in proof it may be mentioned that, upwards of twenty years ago, Mr. George Elliot, M.P., M. Inst. C.E., the President of the North of England Institute of Mining Engineers, strongly urged before a Parliamentary Committee that, in the interests of humanity alone, the offer of a premium by the Government to the inventor of a simple and efficient machine would be well bestowed.

Although this incentive has been withheld, several inventions have, from time to time, been offered for the approval of mining engineers, among which may be noticed the following:—

1st. Filling the bore-hole with quick-lime, with the view of breaking up the coal by its expansion on slaking. This had to be abandoned, from the tedious and uncertain nature of the operation.

2nd. Employing hydraulic pressure in the bore-hole, by means of a pipe passed through a tight-fitting stopper. This failed in consequence of the percolation of the water through the joints and fissures in the coal.

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[1] The discussion upon this and the following Paper was taken together, and occupied portions of four evenings, but an abstract of the whole is given consecutively.

More recently—

3rd. Mr. Cochrane's machine, which may be described as consisting of two metal bars, to be inserted into and pressing against the opposite sides of a bore-hole, about $2\frac{3}{4}$ inches in diameter. Between these, at a depth of 3 feet, was placed a third bar, having a series of inclines upon it on either side, intended to work upon corresponding inclines on the inner sides of the pressing-bars, small rollers being inserted between the inclines to reduce the friction. The centre bar had a screw at the end, with a nut upon it, by turning which it was drawn outwards; and in this manner the opposite inclines acting against each other, through the interposed rollers, caused the outer bars to press against the opposite sides of the hole. The expansion of the faces of the pressing-bars of this machine did not exceed $\frac{3}{4}$ of an inch, which was not sufficient to produce any useful effect.

4th. Mr. Chubb's machine, which consisted of a tube about 4 feet long, and $4\frac{1}{2}$ inches in diameter, with a force-pump attached to the end. The hydraulic ram moved out longitudinally, and was the full length of the tube. The expansion of this machine could not, however, be made to exceed $1\frac{3}{4}$ inch, and therefore it was practically inefficient.

5th. Another machine, invented by Mr. Grafton Jones, was very similar to that of Mr. Chubb, with the exception of the ram, instead of which he used small pistons about $1\frac{3}{4}$ inch in diameter, moving out at right angles to the tube. In this machine the expansion was still limited to $2\frac{1}{2}$ inches or 3 inches.

6th. Experiments have also lately been made by Mr. Farum with a machine consisting of a long wedge, formed like a spear, which, when driven between two guides, with an 18 lb. hammer, required about three hundred blows to bring it home, and even with that force it failed to break down the coal.

Several other machines, working upon the principle of cutting grooves or slots in the coal, have also been tried; but as only partial success has attended these trials, and as the system is essentially different from that under consideration, the machines are not described.

It will be observed that the great defect in all these machines is the limited expansive power, which does not exceed 3 inches, and which in practice has proved to be insufficient for breaking down a mass of coal in a workable state.

Gun-cotton in an improved form has also been used; but even under the most favourable circumstances it has the disadvantage of

giving out deleterious gases as products of combustion, and the mass of coal brought down is broken into as minute fragments as when gunpowder is employed; thus great loss in production is induced.

After fully considering the principles of these various systems and machines, and discussing the whole subject of coal 'winning' with Mr. Elliot, and also with Mr. Craig, Assoc. Inst. C.E., the Manager of the Harecastle Collieries, to both of whom the Author is greatly indebted for many valuable suggestions, and after passing some time in investigating the working of collieries, the Author, assisted by Mr. John Jones, devised the machine now brought under the consideration of the Institution.

This machine (Plate 10, Figs. 1 and 2) consists of a small hydraulic press of 12 tons power, to which is attached a pair of tension-bars, bent in the form of a connecting-rod or hinge-strap. At the other extreme end of these bars, when about to be used, are placed a clearance-box and two metal pressing-blocks, and between the latter is forced, by the action of the hydraulic press, a twin-split wedge, 15 inches long, causing a lateral expansion of 3 inches. If that action be insufficient, the ram is withdrawn, and a second wedge is inserted between the two parts of the first wedge, and is forced up until sufficient expansion is obtained to break down the coal. This operation can be repeated several times if it be found necessary.

The wedges may be formed either so as to cause the pressing-blocks while expanding to retain a position parallel to each other (Fig. 3), or they may be arranged to form a gradually increasing angle with each other, as in the machine before the meeting, as shown in Fig. 4.

In the trials of the machine at the Harecastle Collieries it was found that several minor improvements could be made. The weight of the apparatus could be reduced from 80 lbs. to 50 lbs., and thus enable it to be carried about the mine with facility. To effect this the hydraulic press will in future be made of steel; the ram will be cored out; and the tension-bars be reduced in length and section. In the practical working with these machines, each gang of colliers will be provided with a pair of tension-bars and three wedges. Three or four presses will be quite sufficient for each pit, and these will be applied by the men who at present occupy the position of 'firemen,' and who, at the same time, can give attention to the ventilation of any particular district of the colliery.

The machine now before the meeting was tried at the Harecastle Collieries on the 2nd November, 1868; and the following extracts from a Report by Mr. Craig will describe the results of its practical working:

"On Monday (November 4th, 1868) trials were made in our

7-feet seam. The coal was holed or curved at the top 5 feet in. The bore-hole was punched 4 feet deep and 3 inches in diameter. The machine was then applied, and in about half an hour the coal was completely fractured. Another hole was already punched, and the machine applied, and a similar result followed, bringing down about 10 tons of coal by the two operations.

"We then punched two holes in the 8-feet seam. The first was in a solid pillar. The thickness of the seam is 9 feet. There was no curving, and this was intended as a very severe test of the power of the apparatus. Figs. 6 and 7, Plate 10, represent a plan and section of the pillar, showing the position of the hole. When the first wedge had been pressed in, the coal was cracked, but not sufficiently to be brought down. A second wedge was then inserted and an expansion of 6 inches obtained, and a vertical opening of about 3 inches appeared from roof to floor. A third wedge was then pressed in, and this, without any aid, brought down, in only three, or four pieces, about 12 tons of coal. It was a splendid fall, and to have obtained the same result by blasting, at least 2 lbs. of powder would have been used. The whole time required to apply the machine and to get down 35 tubs of coal was about half an hour.

"We next tried it in a narrow place 7 feet wide, the nicking being in about 3 yards and 4 feet wide; the curving at the top was in 3 feet (Plate 10, Figs. 8 and 9). This was also a good test, being the largest hold that could be taken by a shot in driving a pair of exploring-places which we frequently find give off too much gas to admit of the use of powder. Before the first wedge was driven home, the coal cracked clear off by the curving, and extended about 7 feet to 8 feet along. Before the second wedge was pressed in, the whole block, about 8 feet by 3 feet by 5 feet, opened, and the crowbar was applied by two men, who readily brought it down in three or four blocks. The result was most satisfactory; and about a dozen colliers who were standing by expressed their surprise, and said they never saw a shot produce so good an effect.

"The expansion shown by the sketches is in a wedge form; but there may be an advantage in having a parallel expansion, and wedges are being made to effect this. I am quite satisfied, however, that we have now the right machine, and as it is now made, it is a great success. The power is quite sufficient for any coal.

"There should be three or four presses in the pit; and each set of colliers should have the strap and wedges, which they can apply with as little difficulty as 'stemming' the shot-hole. This done, the press can be applied and the blocks brought down in a few minutes—certainly less time than is consumed by firing and waiting for the smoke clearing. The coal can be nearly all filled as round

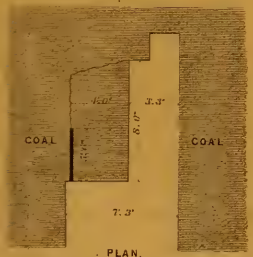
Fig 6.

PLAN.

Fig. 7.

SECTION.

Fig 8.

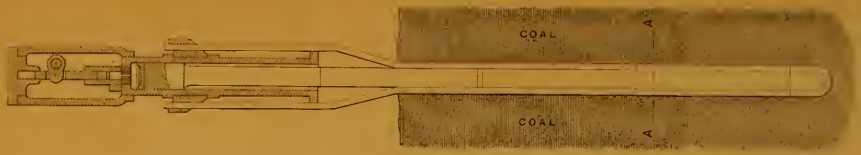


PLAN.

Fig. 9.

SECTION.

Fig 1.

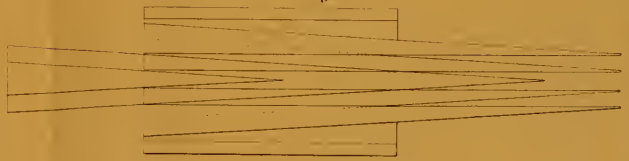


SECTION AT A.A.

Fig. 2

SECTION AT B B

Fig. 3.



PARALLEL EXPANSION.

Fig. 4.

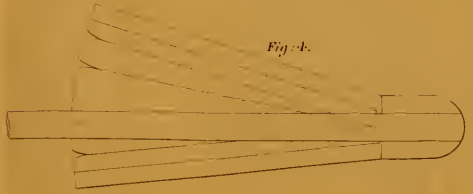


Fig. 5

coal, and the saving from this will be great. The risk of firing will be got rid of, and no new class of labour is introduced.

"The machine is handy, and its application exceedingly simple. I am sure that it may be unhesitatingly pronounced a perfect success."

It is generally admitted that any expense or trouble should be willingly incurred to abolish the use of gunpowder in mines. At all the inquests upon the victims of explosions, the attention of the Government is directed to the subject, but hitherto nothing satisfactory has been done. Recently, at Wigan, the evidence of a well-known coal-viewer of the north of England shows, that the explosion of a powder-bottle materially increased, if it did not initiate, the loss of human life. Yet gunpowder is still employed for bringing down coal. To this the attention of all engineers, as well as to all employers of labour in coal-mines, is directed.

The importance of economising the mineral wealth of England is so universally acknowledged, that no apology is needed for describing a simple method of ameliorating the getting of coal whereby waste can be prevented; but when by the same process an element of security is introduced against the frightful casualties which too frequently occur in using gunpowder for blasting in collieries, the subject becomes more important; and with the object of eliciting the criticism and advice of practical mining engineers, whose attention is incessantly devoted to this important subject, this Paper is submitted.

The Paper is illustrated by a series of diagrams, from which Plate 10 has been compiled.

No. 1,217.—"On Coal Getting Machinery, as a Substitute for the Use of Gunpowder."[1] By CHARLES JOHN CHUBB.

IT is admitted by mining engineers, that the risks and difficulties attending the working of coal-mines have of late largely increased. The greater depth to which many of the pits are now worked, and the vast extent to which the lateral ramifications are carried, have confessedly created difficulties which call for alterations and improvements in the art and practice of coal-mining.

The benefits to be gained by the improvements now needed may be thus specified:—First, To insure greater safety to the men employed in working; and, secondly, to obtain the coal in a better condition, and, by preventing as much as possible the present loss arising from waste, to make more fully available all the remaining resources of the coal fields. These objects, it must be granted, are of the highest interest.

The most fruitful source of all the accidents which occur in collieries, and indeed of most of the evils attending the working of coal-mines, is undoubtedly to be found in the use of gunpowder, and in the operation of blasting. The firing of a shot often checks the ventilation of a pit, and renders increased ventilation necessary, in order to dispose of the foul gases produced by gunpowder. The concussion consequent on the explosion frequently causes injury to the roof of the pit, involving, as a precaution, the adoption of narrow workings, and a heavy expense for props. The act of blasting is frequently the cause of the ignition of gases escaping from the coal at the time of firing the shot; and it is certainly solely in consequence of the operation of blasting that a naked light (to the use of which most of the colliery accidents may be attributed) becomes an absolute necessity in a pit. To the operation of blasting, also, may be attributed much of the loss incurred by the large per centage of small coal now produced, and the imperfect condition of a great portion of the coal generally. The effect of the concussion upon the coal is to shake it violently, shattering some of it into small pieces, when it becomes mixed with the material from the roof, while much of the remainder is so tender that it is peculiarly liable to break when subsequently handled or screened.

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[1] The discussion upon this and the preceding Paper was taken together, and occupied portions of five evenings, but an abstract of the whole is given consecutively.

To abolish altogether the operation of blasting in coal-mines is, therefore, the great change and improvement required; and the problem to be solved is, to ascertain what force can be applied which shall be equally effective, and at the same time break the coal in a more perfect manner. If, in accomplishing these ends, the cost for labour can at the same time be reduced, it will no doubt be admitted, that any suggestion offering a solution of the difficulty is worthy of consideration.

About two years since the attention of the Author was called to the subject, when engaged in coal-mines in South Wales. After investigation, he felt satisfied that some more simple and practicable means of getting coal by mechanical power could be devised than the costly, but skilfully contrived, coal-cutting machines, then being tried with doubtful success. He came to the conclusion, that if hydraulic force could be brought to bear upon the coal from the interior, by a machine of small size, but capable of exerting sufficient force, the coal must yield to its influence, and could be rent asunder in any way that might be required. Following out that conviction, his first idea was to apply wedges, acted upon by hydraulic force; but he found, in practice, that the friction produced by the use of wedges absorbed much of the power, that the wedges themselves were rapidly cut and destroyed, and that the action of a machine thus worked, not by a parallel but by an angular movement, was to imbed its points, when expanded, into the coal, especially into coal of a soft nature, so that a wide expansion of the apparatus was necessary before the coal could be broken out from the solid.

These, and other serious objections to the use of wedges, induced the Author to abandon that system, and to adopt instead an apparatus consisting of several plungers, set side by side in a steel bar, which plungers, when acted upon by water from a hydraulic pump, will separate the bar in which they are set from another bar, formed in the shape of a cover upon the plungers. The pressing apparatus, which has been lately used with perfect and unvarying success, has twelve plungers, and is 25 inches long. It is attached to a hydraulic pump, by a tube 2 feet in length, so that it may be inserted into a hole drilled into the coal to a depth of about 3 feet 6 inches. The apparatus, with the cover on, is $4\frac{3}{8}$ inches in diameter, but it is capable of being expanded to any extent that may be required to break down the coal. When, by the action of the pump, the plungers have reached their limit of $2\frac{1}{4}$ inches, and further expansion is needed, the plungers are readily brought back to their first position by opening an escape-cock for the water, when a liner can be inserted between the plungers and the cover. The operation of pumping again expands the apparatus to the further width of the liner, and this process can of course be repeated *ad infinitum*. The introduction of a liner is a work of no difficulty whatever. It is

done by hand, whilst the pressing apparatus is in the coal, and without detaching the pump. The assertion which has been made that the expansion of this machine could not "be made to exceed $1\frac{3}{4}$ inch" is therefore manifestly incorrect. In practice, however, it is found that the first expansion of the apparatus to $2\frac{1}{4}$ inches is more than sufficient.

In 'getting' coal, it is generally preferred that the excavated material should not be thrown out in the mass; but that it should be cracked and loosened in such a manner that it can be readily removed by hand for 'filling.' This has been for the most part accomplished by the expansion of the apparatus to the extent of even less than 1 inch. If the coal is thrown out, there is risk of injury to the men, and it impedes the operation of filling into the trains and tubs.

The force which the apparatus is capable of exerting will be understood, when it is stated that the collective area of the twelve plungers is 24 square inches, and that the pump can exert a pressure of 12 tons on the square inch; consequently the pressure which can be brought to bear upon the coal is equal to 288 tons.

In the earlier stage of the Author's experiments, he was induced to make a trial in the Harecastle Colliery, Staffordshire, the property of Messrs. Bidder and Elliot. The apparatus used on that occasion was an experimental one, differing in many important particulars from that now in operation, and the cause of the failure, which then undoubtedly occurred, was attributable entirely to the irregularity of the hole which had been made in the coal to receive the apparatus. The difficulty of boring a true hole, $4\frac{1}{2}$ inches in diameter, into any coal, has since been overcome, by means of a drill, by which one man can bore a hole of that size, 4 feet deep, into ordinary coal, in about ten minutes. The hole prepared at Harecastle was 'jumped' out in a very rough manner by a bar, and occupied a man, it is understood, nearly two hours in making. The pressing apparatus then used was not equal to the strain put upon it, in consequence of the irregularity of the hole; and it may be asked, whether such a trial can be fairly referred to as condemning a principle, which had not then been put into practical shape, but which has since been perfected, and is now in successful operation?

Plate 11 will serve to show the action of the apparatus in the South Wales district, where the coal is of the most varied description, and perhaps as difficult to work as any to be found elsewhere in the United Kingdom. The managers of the several collieries have kindly offered to bear testimony to the results which have been achieved, for the most part, in their own presence.

Considered solely in an economical point of view, and not from a higher motive, as a means of preserving life, this apparatus appears to commend itself to the attention of coal-owners. In support of

this it may be sufficient to give the following data: By the present system of blasting, it occupies, on an average, two men ten hours to break down and fill into trains 4 tons to 5 tons of coal, of which 20 per cent., on the average, is 'small,' and so mixed with stone, &c., as to be of little value, while the remainder is much shattered, and therefore more liable to break, when roughly treated, than it otherwise would be. On the other hand, with this apparatus, two men can readily break down 20 tons of coal in one hour, which can be filled, when loosened, at the rate of 10 tons per man per day, the whole of the coal so obtained consisting of large solid pieces. Again, by the present system, in order to break down 500 tons of coal a day, from a 4-foot seam, a 'face' of 600 yards is required, whether as pillar and stall or as long work; and as the several workings containing that amount of 'face' must be kept perfectly ventilated, it is of course an object of great importance if a less amount of face can be made to yield the same quantity of coal, for in that case there will be less space required to be ventilated. This apparatus happily accomplishes this also, for, by its use, 500 tons of coal can be worked out from 300 yards of face, being one-half of the face now required for the same quantity of coal. The working operations of a mine generally can thus be concentrated, and facilities will be afforded for effecting economy in other respects.

In conclusion, it is hoped that enough has been said to impress others with the conviction, that this apparatus will prove to be, at all events, one of the means whereby the use of gunpowder in coal-pits may be rendered wholly unnecessary, and its total prohibition brought to pass, thereby removing one of the chief causes of explosions, and helping to prevent those dreadful calamities which have so frequently occurred of late, and by which so many lives have been sacrificed.

The communication is accompanied by a series of diagrams, from which Plate 11 has been compiled.

Mr. S. P. Bidder, jun., having explained his invention and illustrated the operation of the machine by means of a specimen of the apparatus described in his Paper,

Mr. Chubb said there were three systems of working coal, called respectively the 'single stall,' the 'long wall,' and the 'double stall.' These systems were represented in Plate 11, Figs. 1, 2, and 3, in which the breaks in the coal vein showed the way the strata ran. The white lines represented the position in which the machine was placed in the coal. The first trial was made in the double stall, just over a flat hole then ready for firing, and the machine brought down about 3 tons of coal, as shown by the thin lines in the Figures. The shot itself would probably not have brought down more than three-quarters of a ton. The next trial produced a still better effect. The number of holes made in this stall in three hours was five, and about 25 tons of coal were brought down. The coal was of a hard quality, and extremely difficult to work without powder, the use of which the Government Inspector had prohibited in that pit. In all three systems of working the machine had been successful, and the diagrams represented in the aggregate thirteen trials which had occupied seven hours and thirteen minutes, and produced 88 tons of coals, all of which had been done without the coal being cut as usual either at the top, side, or underneath. In South Wales the most difficult seams to work were 2 feet 9 inches thick, and in some places they could not be worked at all. This machine had recently been successfully tried in one of them, where the coal was so hard that the stone had been wrenched away with the coal.

The machine with all its parts weighed about 150 lbs. He had entertained the idea of the wedge system at first, but having found, by calculations, and from the experiments of others, that the principle of wedges and hydraulic pressure would fail, he had not adopted it. It was not from the failure of any experiment of his own: he had ascertained that a liner was unnecessary, and, in fact, that a stroke of about 1 inch was amply sufficient to loosen the coal.

Mr. Chubb then proceeded to describe a specimen of a new boring tool, in which he said, the upper part of the stand represented the roof of the coal-pit, and the lower part the floor. He had, contrary to general custom, placed the apparatus at an angle, to show that the upright could stand in any position, by a ball socket being put in at the top and at the bottom. To the upright was fixed a brass block nut with a thread made to fit a screw, and on the end of that was placed the spiral drill, the two separate teeth of which were so arranged as to cut an annular space in the coal, leaving a round block in the centre, which was easily broken up, as the sides were loosened by the operation of the teeth. The drill advanced $\frac{1}{6}$th of an inch each revolution, and could be worked by a

boy turning the wheel which ran loose on the screw outside the thread, fitting the key-way running along the screw. As the screw advanced, the boss of the wheel pressed against the nut through which the screw moved, and thus it was kept back and did not advance with the screw. To drill a hole along the rib of the stall, or in a corner, a ratchet was provided, so that it could be turned without the necessity of a support on the wall side of the apparatus. This upright was so made that it could be fitted to any seam from 2 feet 9 inches to 8 feet thick, by placing various distance pieces either at the top or the bottom. One of these measured 3 feet 6 inches long, another 2 feet 4 inches, and a third 1 foot 6 inches, and these three could be combined. The drill was keyed to the screw, so that the screw pushed forward the drill, and turned it at the same time. He had also arranged the screw so that it would work out of the centre of a hollow drill. The end of the screw was fixed in the upright, instead of working through it, which lessened the distance between the working face and the upright, and this in pits with little room in front of the face was of great importance.

Mr. Craig, Manager of the Harecastle Colliery, said, that when the Moss pits at Harecastle were opened about five years ago, and the levels commenced from the bottom of the shaft, great difficulty was experienced from the explosive gas, preventing generally the use of powder, and it was frequently necessary to stop up the places for days on opening out seams which generated large volumes of gas.

It sometimes happened, while driving the first roads, that gas was given off in such quantity and with such force, that sufficient air could not be sent into the place to render it inexplosive. Hence more passages between the intake and the return had to be made as the drifts proceeded, much to the detriment of the ventilation, because every connection required stopping, and that gave rise more or less to subsequent leakage in the main airways.

The machine brought forward by Mr. Bidder did away with the necessity of blasting with powder, and thereby removed a cause of great danger to life; secondly, it reduced the amount of small coal produced by the shot; and thirdly, it supplied the means of expediting the opening of fiery collieries. The trials had been made with this machine in two seams, both of which gave out a large amount of explosive gas. His attention had previously been directed to the machines of Mr. Chubb and Mr. Cochrane. The former had been tried in South Wales, where the coal was of a different character to that at Harecastle, and he was informed it had succeeded there. Repeated trials were made with it at Harecastle, but it was found that the expansion of about $1\frac{3}{4}$ inch, which was all that the machine permitted, was inadequate to bring down

the coal, or to loosen it sufficiently to admit of the crowbar being applied to bring it down. Mr. Cochrane's machine, which was in some respects similar to the other, had proved equally unsuccessful. Both machines required the hole to be drilled perfectly true, and even then he found they were not applicable to the seams he was working. In consequence of the expansive part of the machine extending the entire length of the hole, the plates bent at the front where the coal was tender and the power was expended uselessly.

It appeared that Mr. Chubb had improved his machine, since its failure at the Harecastle Colliery, by shortening the expansive part of the apparatus. He had also produced a drill, by which it was stated, a hole, 4½ inches in diameter and 4 feet in length, could be drilled in ten minutes. That statement was so remarkable, that Mr. Craig could only account for it by the difference of the coal in South Wales from what he had been accustomed to deal with. He could conceive no apparatus which would drill such a hole in the time. The coal of South Wales was of a different structure to that of other districts. It had an earthy fracture, and the lines of cleavage were very distinct, having clear vertical partings, running parallel to each other at intervals of 18 inches or 2 feet, so that but little force was required to bring the coal down, compared with what was necessary to work the coal to which Mr. Bidder's machine had been applied at Harecastle. He had not had an opportunity of seeing Mr. Chubb's second machine at work, or possibly it would have enabled him to modify the views he had expressed with regard to the original apparatus.

After trying the machines referred to, he directed the attention of Mr. Bidder to the matter, and the result was the production of a machine which allowed considerable expansion, and did away with the necessity for finely-drilled holes. The hole which the collier was accustomed to punch for the powder shot sufficed for the admission of the straps, and the fireman who now fired the shots, or even a lad of twelve years of age, was competent to apply the ram. He found that it required two wedges and an expansion of 6 inches to produce the desired effect. Experiments convinced him that the whole process could be effected by this machine as quickly as by the use of powder, if not more so; in fact, as there was no smoke, he believed there might ultimately be a saving of time. Where powder was used an interval of about ten minutes elapsed before the smoke cleared away sufficiently for the colliers to resume work. In mines of bituminous coal one source of danger in firing was the starting of the gas in goaves or hollows where the coal had been worked out, and the superincumbent strata had fallen in. Cavities were thus formed in the roof where gas collected, which no ventilation could clear

away so as to prevent danger. He had been called upon to examine a pit in which seven men were killed by the firing of a shot. A great fall had taken place at the face of the coal, and, although it had been forbidden, the men had fired a shot which blew out the stemming and caused an explosion. The verdicts of the juries frequently bore testimony to the fact, that although there was not sufficient evidence to enable them to arrive at a reliable opinion as to the immediate cause of explosions, there could be no reasonable doubt that they were really due to the firing of shots; and they were often accompanied by strong recommendations, that gunpowder should no longer be used in coal-mines. The difficulty of accounting for explosions would always be felt, because the results of an explosion rendered it impossible for any one, however skilled and sincere in such investigations, to ascertain the exact cause. Although the selection of a class of men of superior skill and integrity for firing the shots might prevent accidents from the direct ignition of gas, by the projection of the flame from the shot, there was a source of danger, far more subtle and serious, to be apprehended from the concussion of the shot dislodging gas from the goaves, and bringing it into contact with naked lights, possibly hundreds of yards distant from where the shot was fired. He had known the flame and smoke of a furnace affected by an ineffectual shot fired at 500 yards distance; and of a man who had his hat blown off his head by the concussion of air caused by the discharge of an ineffectual shot fired at a long distance from him. It therefore appeared to him of great importance to provide some substitute for gunpowder which would not produce concussion, and he thought the machine invented by Mr. Bidder, would secure all the advantages of powder without its concomitant evils.

He would now briefly point out how its adoption led to the saving of cost. It was important that the main roads in a seam of coal should be well supported and kept open; and this was particularly the case in steep measures, where a single level was often applied to a large district of coal, from which no deviation was possible without getting above or below the level of the bottom of the shaft. The longer these levels could be kept open without timbering the better; because when the roof began to fall and timbering was required the cost was greatly increased; not so much owing to the price of the timber and the labour of setting it, as in the frequent stoppages to the work. Suppose a seam of coal, where the inclination was 1 in 4 and levels were carried on each side for 500 yards, was opened for a width of 100 yards in a 6-feet seam, there would then be an aggregate of about 200,000 tons of coal which must pass along those levels. It would take about twelve months to drive those levels, and after having driven them there

must be two 'jigbrows' or roads, in the line of the full rise and dip, kept at work on each side to enable 100 tons of coal a day to be sent from each side of the shaft. These levels would require to be maintained upwards of three years, and each jigbrow for about fifteen months. Now when these roads were driven by powder they soon failed. The continual tremor through the shale roof occasioned by the shots caused it to fall: and when coal was left at the roof to support the shale above, as was always the case when circumstances admitted, it became so shaken that usually in twelve months' time timber was required for the maintenance of the roads. Whereas roads driven without powder would stand for two or three years. It was therefore important to find an efficient substitute for powder, which would not occasion this vibration and consequent weakening of the roof.

With regard to the saving of time, the last trial by Mr. Bidder at Harecastle Colliery was upon a block of coal 10 feet long by 3½ feet wide; this was quickly brought down by one operation; whereas if powder had been used, two shots at least would have been required. This he attributed to the difference of the two forces employed. When powder was used, a force was put in action sufficient to overcome the coal in the line of the maximum cohesive resistance, and the instantaneous exertion of such force prevented the coal from splitting in the direction of the line of cleavage, breaking it short across in several pieces; but in this machine, force was accumulated by the gradual insertion of wedges, which gave time for the coal to break up in the direction of the line of cleavage, which was that of the least cohesive resistance; and when applied in a bed of coal, where the line of cleavage was distinct, it had greater effect than powder. He thought it probable that a single application of the machine would be equal to two or three blasts by powder; and this would result in a saving of time. The economy consisted principally in the gentle removal of the coal from the face by a continuous pressure, instead of the sudden blow from the explosion of powder. There was one point, however, in Mr. Chubb's recent machine that required notice; that was, the increased expansion obtained by the introduction of liners. If the expansion was found insufficient—and it was insufficient for the Harecastle coal—he had to release the force and introduce a liner. Now in releasing the force it was clear that the coal in most cases would to a great extent resume its normal position, and instead of getting in a liner equal to the full expansion of the machine, he would probably only get in one half: and there must be loss of time in releasing the force for the introduction of these liners. Then the apparatus was so constructed that it required entire removal from the hole before it could be applied elsewhere; whereas with Mr. Bidder's machine, to obtain increased expansion,

no release of the pressure on the coal was necessary; the coal being kept in tension all the time that preparations were being made for the introduction of the second wedge, as indicated by its cracking; and when the second wedge was pressed it was driven in with ease: therefore increased expansion with Mr. Bidder's machine entailed no loss of time. The apparatus did not require to be removed out of the hole to proceed elsewhere, which was important when applied to a thick seam of coal; for in such a case it was not safe to bring down the coal bodily, but rather to bring it into a state which would admit of its being pulled down by the crowbar. All that was necessary in reapplying Mr. Bidder's machine was to unship the jack which was attached to the straps outside the hole; and the colliers took out the straps as the coal was removed, which must be done before they were ready for another application of the straps and wedges remaining with each set of colliers. When he called Mr. Bidder's attention to that matter, he suggested that the machine should not exceed 3 inches in diameter, that it should admit of a lateral expansion of 6 inches, and be capable of being managed by ordinary workmen. Mr. Bidder had, by repeated underground examinations, made himself acquainted with all the circumstances which must necessarily govern the application of the machine, and had succeeded in producing a simple and efficient apparatus.

Mr. J. T. Woodhouse said it was almost impossible to overrate the value and importance to coal-mining of these inventions; though he was not prepared to express an opinion on their relative merits. Nor was he aware, though largely connected with coal-mining, how far these inventions had been tried or adopted. He concurred generally in nearly all that had been said, with reference to the safety of the machines as compared with gunpowder. Of course in machinery worked by water there was no fire, and there could be no explosion from powder. It often happened that the goaves could not be ventilated, but were partly filled with explosive gas; so that when a shot was fired, the flame was driven back into the goaf, and fired the gas, from which grievous effects had on many occasions been produced. These water-machines would do away with that danger, and there would be no explosions from that cause. The extent of economy would depend upon the way the machine was applied, and upon the character of the seams, as no two seams were alike. Thus the coal in some was cubical in its fracture, while in others it was long in grain, as the hard steam coal of Derbyshire; again, some coal required mechanical means to bring it down, while other coal could be dislodged with very little force. But under any circumstances, though he could express no opinion, without further trial, as to which machine was likely to be most practically useful,

he thought all the machines were of great value in an economical point of view. In the Midland district there were plenty of opportunities for experiments on all kinds of seams, and he should be happy, as far as he was personally concerned, to render every assistance in bringing these machines into operation. He might say, by way of caution to the inventors, that although the machines presented a remedy for many difficulties, yet there were some things they could not do, as, for instance, they would not undercut or hole the coal. It had been assumed that one of these machines was so complete, that it had only to be inserted into the face of the coal and out would come the piece. But it would be found that it was not so. To tear out a piece of coal from the face was a violent operation, and sometimes attended with wasteful results. The most economical way of working coal—particularly on the long wall system—was to employ a cutting-machine. There were several sorts of cutting-machines—not the hammer which struck a blow, but a slotting-machine—one of which was in use at Kippax Colliery, near Leeds. That machine undercut the coal, with but small waste. If, after this, the machine was applied horizontally with a steady pressure, the coal would come down of any size that was desired, and by this means the largest amount of round coal would be obtained. In addition to the inventions of Mr. Bidder, Mr. Chubb, and Mr. Grafton Jones, there was another machine, by Mr. Bartholomew, of Doncaster, with which he was accidentally made acquainted recently.[1]

Mr. S. P. Bidder, jun., in reply to an inquiry, said that in his machine the so-called straps passed continuously round the cast-iron nozzle, and the lateral pressure of the wedges was exerted between the straps, which received in tension the endways pressure of the hydraulic ram.

Mr. Grafton Jones had for some time past given attention to the breaking-down of coal by mechanical means to avoid the use of gunpowder. The first apparatus he constructed for the purpose consisted of a wedge between segments. The wedge was moved forward by a hydraulic ram, so as to force apart the segments, and thus break down the coal. In a ram apparatus which he next tried, if the hole bored in the coal was not made perfectly true, the instrument was invariably bent to the form of the hole, the ram in this case being permanently injured, but the wedge, which was an extension of the ram, could be straightened. He had now constructed an instrument which would not bend. The holes were bored through the barrel, and in each hole there were two rams, and the water was introduced between them. The thrust was taken on the ends of the rams in a direct line, and they adapted

[1] *Vide* p. 135.

themselves to the hole whatever the shape might be: so that no bending strain was communicated to the barrel of the instrument, as was the case when a single ram was used. A machine, which had been in successful operation for some time, had brought down 7 tons of coal in one operation in a 5-feet seam, and it was capable of being worked by a boy.

In reply to an inquiry, Mr. Jones said he had not noticed that there was any leakage in the instrument. In working Welsh coal a lateral stroke of 3 inches, at the utmost, was all that was required, and that was sufficient to break down any coal he had met with, so that it could be dislodged with a crowbar afterwards. If further expansion was needed, the rams could be drawn back, and a liner be introduced over them.

Mr. R. Mallet asked how the small plungers were drawn back again after having been pushed out through the cup-leathers? If the coal was not broken the plungers in Mr. Grafton Jones' machine would be embedded into and be more or less gripped by the coal; they must be brought back again flat for a fresh pinch, without withdrawing the instrument, in one machine and in the other, before the new-lining piece could be introduced.

Mr. Beardmore remarked that the pistons in Mr. Chubb's apparatus worked with two liners of plate iron, so that the instant the relief cock was turned, and the pressure removed, the machine could be drawn out of the bore; it could not be otherwise when the pistons no longer pressed against the plates. It should be noticed that in all Mr. Chubb's experiments the coal was broken down without any undercutting.

Mr. Grafton Jones remarked that the water was forced from an air-tight chamber which formed a partial vacuum, and as soon as the communication was open with the chamber, the rams were drawn back by the water returning into it. Tangye's pump was constructed upon that principle.

Mr. Warington Smyth said it fell to his lot to visit as great a number of different workings of coal in a year as to most men engaged in mining operations. He was afraid the firing of shots was frequently made the scapegoat upon which the blame was laid of many of the accidents in coal-mines which were really not due to the combustion of powder. It was not unfrequently the case that when the absolute cause of explosion was involved in mystery, the firing of a shot was referred to as the most probable cause. He would be far from saying that the introduction of machines of the nature of those exhibited would not be an immense boon to collieries in regard to that point, since not only was there danger in the fact referred to by Mr. Woodhouse of the striking back of the flame to the neighbouring points of the goaf; but not unfrequently in advanced drifts, carried on as a method of preparation

and exploration in collieries, gas was tapped and issued through the bore hole in such quantity, that, if inflamed, it taxed all the energy of the persons employed in driving the shaft to extinguish it. The most calamitous explosions had taken place in these advanced workings, in consequence of sudden incursions of gas; and supposing even careful overmen were employed for the purpose of firing the shots, he would point to the fact that there might be stored up in fissures in the coal, under high pressure, such a quantity of fire-damp, that though at the moment of loading the charge and firing, everything might appear safe, still, when fired, gas might be released in quantity sufficient to produce an explosion the extent of which it was impossible to predict.

With regard to the economy undoubtedly to be introduced by a 'falling' apparatus, he premised that there were numerous collieries in the west as well as in the north of England where powder was never used as an habitual practice; where the whole of the coal was got by wedging; and where it came down with the application of that simple mechanical force, in fact a large quantity almost fell of itself after undercutting. But where powder was customarily employed, the result in economy from the use of these machines would be considerable; and he looked with interest to further trials in some of those mines where the coal was so tender that the use of gunpowder produced from 20 per cent. to 50 per cent. of small coal. There were coals in some parts of the country, where it became a question with the managers, whether they should continue working the seam, in consequence of the great amount of small coal produced. Under such circumstances gunpowder could not be employed with advantage. If it was used, the coal was so shaken throughout, that it would ill bear carriage, or even exposure to the air when stacked, and thus a large quantity of small coal was produced. The machines would be invaluable for securing a larger proportion of round coal and avoiding waste. As Mr. Woodhouse had remarked, it was difficult to decide on the relative merits of the machines till they had been brought more into play; on the whole, he thought Mr. Bidder's appeared to be an efficient substitute for the common wedging system, in those seams where the present plan was found to be inefficient, and where, although powder might be efficacious enough, it was attended with great want of economy in producing a large proportion of small coal.

The collieries in the west of England, to which he had alluded incidentally, included a considerable area in Somersetshire, belonging to the Prince of Wales, and in the Forest of Dean. These were almost entirely free from fire-damp, so that there was a remarkable immunity from accidents from explosion. The Inspectors of Coal Mines were impressed with the desirability of introducing other methods than the use of gunpowder for breaking

down coal; and in one colliery the Inspector had gone so far as to desire that no powder should be used for bringing down the coal —no doubt much to the inconvenience of the owners. There was abundance of evidence scattered through the reports of those gentlemen, that in mines where powder was used, accidents were of most frequent occurrence. It would, however, be difficult to assert that where wedging was employed without the use of powder, and where the coal was of a fiery character, there was a smaller number of casualties. It would scarcely be fair to judge by the ratio of the number of accidents which had occurred to a certain number of men employed, and to infer that the one system was preferable to the other upon a statistical return, in consequence of the great variety of condition and character of seams that were worked.

Mr. H. Johnson stated, through the Secretary, at the request of the "South Staffordshire and East Worcestershire Institute of Mining Engineers," that, after hearing at Dudley the lucid description by Mr. Bidder, of his invention, a unanimous opinion was expressed, in a full meeting of the practical mining engineers of the district, that it was an invention of the highest practical value, in economizing the working of coal, improving the produce, and preventing the deplorable accidents that result from the blasting of coal by gunpowder; and that they had every confidence in the ultimate utility of the invention both in thick and thin seams.

Mr. A. Lupton observed, that 1,484 lives were lost in the year 1866 in connection with coal-mining operations; but out of that number only 34 deaths were directly traceable to the use of gunpowder. In the case of 120 lives lost by explosions of fire-damp, where the direct cause of the explosions was not ascertained, it would be unfair to attribute the whole to gunpowder; but on the supposition that one-third were so caused, it would raise the number to 74. The total number of men and boys engaged in coal mining exceeded 300,000, so that only one life per annum in 4,000 was lost from the use of gunpowder in collieries, a very small proportion in comparison with the death-rate of large towns.

The machines under discussion were of great ingenuity, and he believed they might come into extensive use; but although powder did not entail so many disastrous results as some thought, he might state that in the coal-fields of Derbyshire and Yorkshire, the mining engineers and managers had for some years past decided that it was not right to subject the miners in fiery mines to the risk of accidents from blasting. Recourse had, therefore, been had to the use of those natural forces which existed in every coal-mine—the weight of the superincumbent strata. When the coal was holed, or undercut, the weight of the rock on the top tended to bring it down, and

if a pit was properly laid out, it often happened that no other means were necessary to effect this. Fig. 1 represented a section of a stall in a coal-pit in good working order on the long wall plan. The face was from 100 yards to several hundred yards long. The black part indicated a seam of hard coal 3 feet in thickness. The lighter colour (lettered 'roof') indicated a seam of inferior coal, and above that was the rock. A little to the right a pack of wood supported the roof, and this was sufficiently elastic to allow the roof slightly to subside, and put a pressure on the coal that was undercut, when a comparatively small mechanical force sufficed to break the coal down, and that was effected by the old-fashioned contrivance of a wedge and hammer. Several holes were made in the coal with a pick, into each of which a wedge was inserted; these were then driven in simultaneously, all being kept tight, when the coal was brought down. The amount of the fall of coal and of the size of the coal under this operation depended upon the distance apart of the cleavage planes—9 inches, 1 foot, or 2 feet, as the case might be. In the seam of coal shown in Fig. 1 a man might bring down about 30 cubic feet, with four wedges, in ten minutes.

Fig. 1.

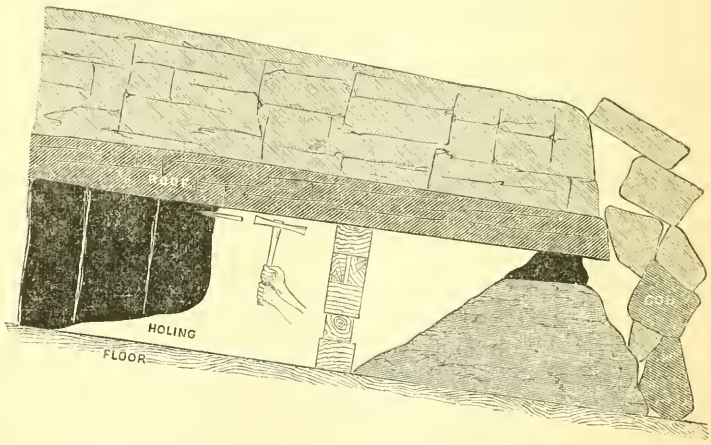
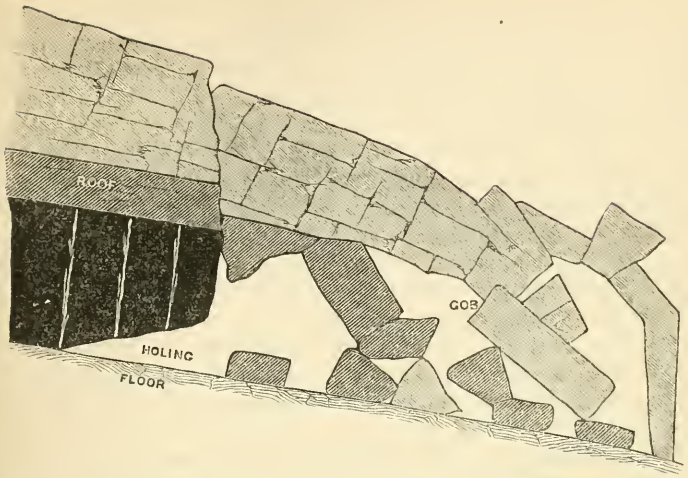


Fig. 2 showed a portion of the mine where the superior stratum had been broken through, and the rock had come down. To break down the coal in this case great mechanical power was required. Therefore it was the object of the collier to keep the roof up as well as he could, so as to throw the weight upon the coal he was working. The cost of the wedging was computed at sixpence per ton in this pit. If the inventors of these machines could prove that their operations could be effected at less cost than

Fig. 2.



The seam shown black is hard coal. The vertical white lines in the coal show cleavage planes. Scale, ¼ of an inch to 1 foot.

that, it would be a good thing for the owners. But many seams could not be worked in the way he had described. In the hard seams the wedges did not sink into the coal, but broke it down at the 'slines.' In a soft seam of coal, however, the wedge only broke off the coal in little pieces, and to get the coal in lumps, it was necessary to apply a force at the back of the piece to be brought down, by boring a hole into it about 3 feet in depth, and there gunpowder was applied; but if the pit gave off gas then there might be danger. In such cases the machines would be of great use in breaking down the coal. Although the machines would be most valuable in pits where the coal was fiery, yet where the coal did not give off much gas, they would come into competition with gunpowder, gun-cotton, nitro-glycerine, and other explosive materials. It was urged in favour of these machines, that shots knocked the coal into slack to the extent of from 30 per cent. to 60 per cent. But a careful collier did not knock the coal into slack. A good collier, so to speak, eased the coal down in lumps, and applied only sufficient powder to do the work. These machines would be a great boon to owners where the colliers were careless; but on the other hand, where the colliers were careful, powder, or some other explosive substance, would maintain its position, unless the machines could be shown to do the work at less cost.

With regard to the relative merits of the three machines, it appeared that Mr. Bidder's and Mr. Chubb's gave out about the same amount of force. Mr. Chubb's exerted a force of from

200 tons to 300 tons for a distance of 2¼ inches; and Mr. Bidder's a force of 75 tons for a distance of 9 inches. Mr. Bidder's machine had been tried in soft coal, and a large measure of expansion was apparently required in getting it down. The ends of the expansion bar probably sank into the soft coal. If it was modified to prevent sinking so much into the coal, it might increase the facility of bringing the coal down. Mr. Grafton Jones' machine appeared to be the most powerful of all, inasmuch as with the same pressure it expanded nearly twice as much as Mr. Chubb's, having rams on both sides of the cylinder, giving from 3 inches to 4 inches expansion. He had no doubt all three machines would be of use in the different localities for which they were best adapted. It would be well if the inventors would give some idea of the cost per ton of getting the coal. A saving even of a penny per ton would, in some collieries, amount to £1,000 a year; and unless a saving were effected to that extent, he did not think the machines would make much way.

Mr. Bramwell inquired whether, in those cases where the coal was brought down by its own weight, it was necessary to hole the coal underneath to the extent shown in Fig. 1, and whether the portion holed was thereby made into waste? Also whether, in the event of these machines being used, it was necessary to hole the coal to the extent there shown? It would appear from Fig. 1, that a large per centage of the seam was broken into small coal by that operation.

Mr Lupton said a large per centage was waste. The amount depended upon the character of the seam. If it was steam coal, the slack was comparatively valueless; if bituminous, suitable for coking, the slack was as valuable for coking as the large, though it sold for less. As a rule, the waste from holing was considerable, but holing machines had been introduced, by which the waste was reduced to a minimum, the cut being only 3 inches wide. He did not know if they had proved generally successful; indeed it required an excellent machine to make way with coal owners and managers.

Mr. Chubb said he had worked 300 tons of coal with his machine, and had never in any case had occasion to hole the coal, or to cut it. In one trial only had there been any cutting, and that was where an experiment was hurried in order that an owner might witness it. A few days previously the machine had been tried in a seam 2 feet 9 inches thick in South Wales, where, from the great hardness of the coal, it had to be holed, when gunpowder was used; but with the machine it was not found necessary.

Mr. S. P. Bidder said, in a trial with his machine, in pillar working, where the seam was 9 feet high, the hole to take the machine was made 6 feet from the side, and 4 feet from the bottom. No

holing was required, and the block brought down was 5 feet high by 4 feet wide, and 8 feet long, and weighed 12 tons. Although in pillar working no holing was necessary, in drift work he thought holing expedited the formation of the roadway.

Mr. Bramwell remarked that, in the year 1864, Mr. Bartholomew, impressed with the danger of using powder, proposed to apply hydraulic pressure, in a way which was stated by Mr. Bidder in his Paper to be unsuccessful. Mr. Bramwell was surprised to hear that, because it appeared to be the natural way of doing it, if it would answer: that was, first to make a hole in the coal by some boring tool, then to put in a special tool which would chamber out a disc at the extremity of the first hole, and afterwards to apply hydraulic pressure. He thought if this chamber were hollowed out to a sufficient area, the beginning of the crack might be set up by putting on the water pressure; and, as Mr. Bartholomew said, that might be done with the head of water which the height of the pit would give. Besides, Mr. Bartholomew proposed to lay hold of the coal by a species of gripper; and Mr. Bramwell thought, from reading the specification, that the plan was practicable. Then there were the machines of Mr. Grafton Jones, Mr. Chubb, and Mr. Bidder. The machine of Mr. Jones exerted a certain amount of force, on a definite area, by separate pistons at right angles to the axis of the tubes by which they were introduced. He understood in hard coal it did that which was wanted; for though hard coal required more power to break it, the work done was not so much. The trials of the steam ploughs at the Exhibition of the Royal Agricultural Society, in the summer of 1868, afforded an illustration of this. Last July the earth was baked as hard as stone, but it was a fact that the power required to plough that earth was less than was expended in ploughing through the soft earth four years before; because when it was separated, it was done by the application of considerable power, but acting through no great distance; and he understood that to be so in respect of hard coal. In soft coal he feared the plungers would bury themselves. Then Mr. Chubb proposed to put a cover over the plungers, so as to increase the surface of pressure on the coal; but he thought Mr. Bidder was the only one who had brought forward a cumulative apparatus — that was, an apparatus in which, if the amount of expansion in the first case was not sufficient, that amount of expansion could be increased without withdrawing the apparatus from the work. He did not think either of the other machines provided for that. If the expansion were not sufficient in those machines in the first instance, the tool must be withdrawn and lining pieces be added, but to do this the pressure must be taken off; whereas, with Mr. Bidder's machine, if the expansion were not sufficient at first, further

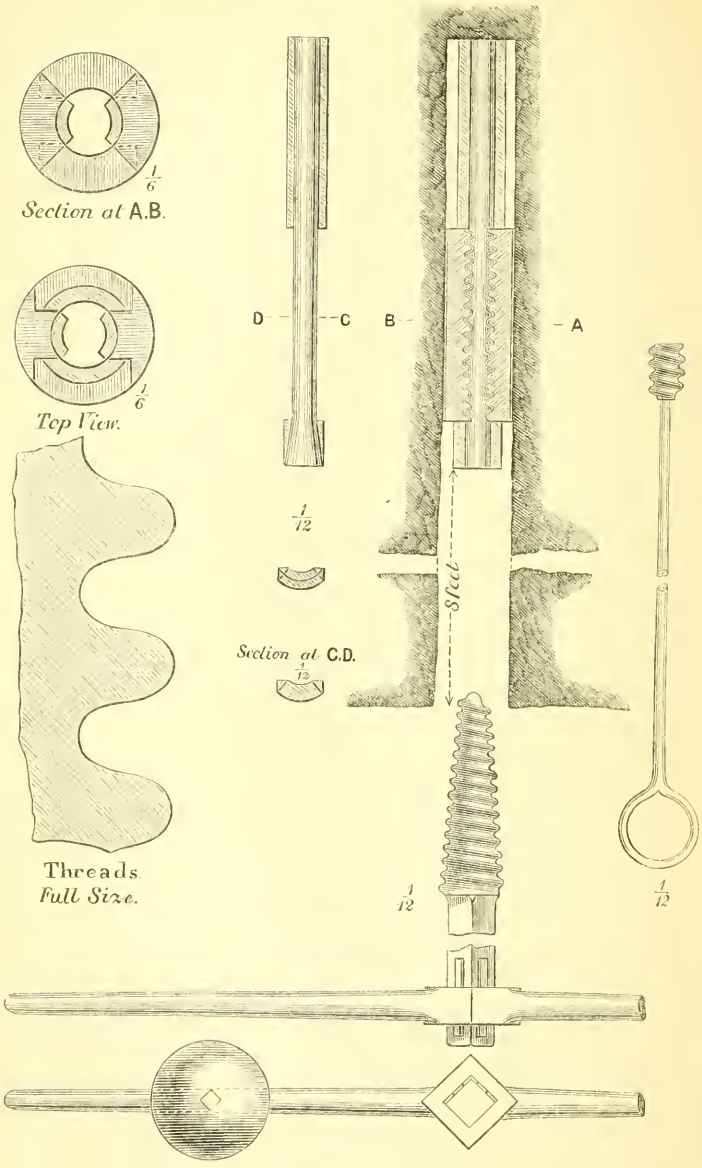
expansion could be got without the necessity of removing the machine, or taking out any portion of it. It seemed to him that, in that particular, the machine of Mr. Bidder should be preferred for the general qualities of coal, rather than machines which did not admit of indefinite expansion; though he believed, with hard coal which did not require pressure through a long distance, the other machines might be equally applicable. The practical and scientific men who had taken part in this discussion appeared to be unanimous in the conclusion that, though powder was not the cause of all the mischief attributed to it—any more than the admission of water into red-hot boilers was always the cause of explosions—yet that it did frequently give rise to loss of life, and did cause the conversion of a considerable quantity of coal into slack. No one during the discussion had suggested, that the use of hydraulic machines would either endanger life or increase the amount of slack; nor had any one suggested that the cost of working coal would be enhanced by the use of these machines. On the contrary, an element of danger to human life was avoided, and the risk of good coal being turned to slack, by the improper use of powder by careless and indifferent workmen, was obviated. Although he was aware that slack of bituminous coal made good coke, he was not aware, till he heard the statement from Mr. Lupton, that it was of equal value at the pit's mouth with good coal. These were the points which these machines suggested to him. He had very little doubt that, being brought before this Institution, and as a consequence before others, the attention of miners would be directed to them, and that, in the cases to which each machine was more particularly applicable, it would be used to the saving of life and to the economy of coal.

Mr. R. Mallet wished to mention, as a contribution to the history of the subject, a still earlier invention for breaking down coal than any which had been noticed. Mr. Joseph Bramah, the inventor of the hydraulic press, proposed, for this and other like purposes, the use of a bag formed of reduplicated leather and fitted with a nozzle. This was to be placed in a suitable cavity hewn out in the coal; and then water was to be admitted to fill the bag, and hydraulic pressure was to be applied by a pump. He had some reason for believing that this method was actually tried, with what success he did not know, in one of the Staffordshire collieries, though he apprehended the contrivance, in common with those now before the Institution, was least adapted for thin seams, such as those of Staffordshire chiefly were. Of course no one would think of reverting now to this somewhat primitive arrangement, but it was interesting as one of the inventor's early previsions of the applications of the hydraulic press.

As part also of the history of instruments for the mechanical division of mineral masses, such as rock, or coal, Mr. Mallet wished to place upon record his own proposal of a conical splitting screw. Many years since, at a time when Irish slate quarries began first to be worked, and when it was found that, owing to the dense and shivery character of the geologically old Irish slates, they were greatly shattered and enormous waste produced by the use of gunpowder, he had exhibited these splitting screws in use before Field-Marshal Sir John F. Burgoyne, Bart., G.C.B., then Colonel Burgoyne. This was in the first year of Sir John Burgoyne's Chairmanship of the Board of Public Works in Ireland; and at that time a block of the dense argillaceous limestone of County Dublin, a cube of about 4 feet, was split in halves by two men, with one of these screws inserted in a single hole of about $2\frac{1}{2}$ inches diameter, in a few seconds. He had not, however, followed the invention up, nor was he aware that it had been employed by others, or was even generally known.

The apparatus was simple (Fig. 3, p. 138):—A long cylindrical nut, or tube of some inches in length, had a female screw of suitable pitch cut throughout its interior. This nut of wrought iron was either then, or previously, split longitudinally into four equal segments by sections, parallel to the axis, and this formed two working nuts of two segments each. Two of these segments were placed in the respective positions they occupied before, and were kept in position by two intermediate filling pieces of soft fir-wood. In this way the actual nut was formed, and was held together by two or more rings of thin binding wire of iron lapped round it, and the whole was thrust down to the bottom of a hole, drilled or jumped into the rock, slate or coal, in the usual way. The diameter of the hole might vary, but advantageously was about $3\frac{3}{8}$ inches. The fir filling pieces projected below or beyond the nut to such a distance as it was desired to keep the nut from going to the bottom of the hole, while allowing the conical screw to pass to its full depth. The conical screw intended to enter this nut had, at its smaller end, the same diameter as the latter. It was several inches in length, and the upper or larger end was of such diameter, that the mineral mass should yield by or before the time that this upper end, upon being screwed into the nut, had reached the middle length of the latter. The conical screw was made of hardened steel, and its upper end was prolonged into as large a square shank as possible, by which, and by the aid of a double-ended wrench adaptable to it, the screw could be turned and forced in, by manual power applied at or near the mouth of the jumper hole. The wrench was provided also with two cast-iron balls, at mid-length of the arms, so as to act upon the screw percussively, and so overcome the friction of rest,

Fig. 3.



Conical Splitting Screw.

like the so-called hammer of the breech-plug handle of the Armstrong guns. The nut being in place, the screw was inserted, and it was then a mere question of power, whether the surrounding mineral mass should yield or not, by the force of the conical screw tending to separate the two opposite segments of the cylindrical iron nut in the direction of the transverse line joining these. The friction between the interior of the hole and the exterior of the nut prevented the segments turning with the screw. The force available by this combination was practically very great; it was obviously that of a wedge whose terminal angle was equal to that of the cone of the conical screw, urged forward by the power as applied to a screw of the given pitch, and with the given leverage of the wrench. The resistances were the cohesion of the mineral mass, and the friction of the conical screw at its bearing surfaces against the threads of the cylindrical split nut. It was obvious that a conical screw could only work into the threads of a cylindrical nut, by allowing a certain amount of play in the threads, or between the nut and the screw. But as the pitch was relatively large, the threads rounded, and the angle of cone of the screw very moderate, no difficulty was found to arise from this, beyond a rather more rapid wear of the threads of the nut than if they all bore uniformly at the same time, as in a common nut and screw. The nut was made of soft wrought iron, in order that it might bend, if distorted against a partially-yielding mass, without fracture. At the present day these nuts might be cheaply made in wrought iron. Originally he had proposed to make the nuts of wrought or of malleable cast iron; the threads in the latter case being formed by casting the iron on to the already screw cut surface of a wrought-iron cylindrical male screw, of the required pitch and length, laid into the mould. All mechanical combinations such as this, when acting against a dead and compressible material, such as coal, would necessarily act at great disadvantage, so much so, that he would, for such purposes, prefer the direct application of one or more hydraulic pistons. But for the quiet and economic splitting asunder of any hard, dense mass, such as roofing slate, or certain rocks, he believed that these conical screws, as well as the hydraulic driven wedges proposed by others, might be, with advantage, occasionally employed. The disadvantage of the wedge driven by pressure, as well as in a less degree of these conical screws, was, that the point of action against the resistance was almost limited to one end of the wedge, and partly to one end of the nut of the conical screw. Much power was thus wasted in mere disintegration of the resisting material, if that was of a soft and friable nature, such as coal.

Recurring now to the general subject, nothing, as it seemed to him, could be more pertinent and important than the remarks made

by Mr. Woodhouse and Professor Warington Smyth. It seemed to him, from the limited observation and experience he had of coal mining, that any attempt to split out the coal by wedges or hydraulic contrivances, without previously freeing it from either the roof or from the seat, (that was the upper or the lower beds adjacent,) must prove a failure; for as far as he had seen of the working of either hard or soft coal, it was absolutely necessary that it should be so freed in some way before it was attempted to dislodge it, otherwise there would be great waste, in time, labour, and in the coal itself. If the coal were so freed, the mass would soon part and drop loose by its own weight. In such cases, he did not see much advantage or many applications for the use of wedging. Mr. Warington Smyth and himself had spent a whole night and a large portion of the next day in the Hetton Colliery, near Fence Houses, Durham, looking at Donnisthorpe's coal hewing machinery at work. The coal hewing, on that occasion, upon seams about 4 feet to 5 feet thick, was very satisfactory. About 30 feet in length, by $3\frac{1}{2}$ feet to 4 feet in from the wall face working, was rapidly undercut for a width of 4 inches or $4\frac{1}{2}$ inches, and no sooner was the coal thus undermined, than the block parted from the roof and from the rest of the seam, and the block came down by its own weight, and only needed breaking smaller for removal. In the case of exceedingly hard coal, such as the anthracite of Kilkenny, nothing but gunpowder would break it out of the seam. It was nearly as hard and difficult to dislodge as the highly resisting carboniferous limestone in which it was embedded. In somewhat softer coal wedging would no doubt be more effective, but the advantage would much depend, amongst other conditions, upon the hardness, softness, nature of fracture, or quality of the coal, and he apprehended that the machines, if employed upon very soft and tender coal, would produce a great deal of slack, though possibly less than blasting with powder. He would only add, that Mr. Bidder's diagram suggested some interesting theoretical points. A large portion of the actual work done upon the back of the wedges, would obviously be expended uselessly upon the coal, and more and more as the total angle of the wedges increased; when this became large, not much more, in fact, than the upper corner of the wedge would act effectively in splitting the coal. On the other hand, the action of the plunger system was the same in direction and equally effective, all through the range. He thought a great deal of the effectiveness of Mr. Bidder's wedges would depend upon the angle chosen for each wedge. It was a dynamic truth that the sharper the angle of a wedge driven by pressure, the less would be the useful effect, or relation between the power expended upon the wedge, and the work done by it; because, though the friction was the same within the limits of abrasion,

whether the surface was larger or smaller, still the smaller the angle the greater would be the distance through which the wedge must be pushed to obtain a given increase of breadth. It followed, therefore, that there must be some point at which the angle of the wedge would be the best possible, and hence it would be better, probably, to apply a large hydraulic power to the end of a blunter wedge, than to use a much smaller power to drive in a longer and sharper wedge. Mr. Bidder had not, apparently, investigated that point; but it appeared an important condition to the best success attainable by his invention.

Mr. C. W. Siemens remarked that it was of the greatest interest to all that coal should not only be got economically, but without involving human suffering. Although it had been asserted that the casualties caused by the explosion of powder were not so numerous as might have been supposed, nevertheless it was acknowledged that there was a serious loss of life every year. Independently, however, of that, there was the question of annoyance and injury to health that might be produced by noxious vapours arising from the explosion of powder in confined spaces. Moreover, it had been shown that coal could be got more economically by wedging than by blasting. The quantity of coal released by wedge action must be greater than that released by explosions, inasmuch as powder threw out the cone of least resistance, whereas a wedge would exert its power upon a larger range of coal. The question of undercutting the coal was no doubt important. He had been endeavouring to calculate what force would be expended in each case, but he had not been able to obtain a satisfactory result. If the coal was holed, or undercut, a disc of it had to be dealt with, and with the wedge the line of cleavage would be contained in that disc. He expected that the force expended would increase with the depth at which the force was applied; so that if the machine was inserted into a hole 4 feet deep, it would expend four times the force that it would if the machine was put in only 2 feet deep. But the question became much involved if the coal was to be torn out of the face, because then the top and bottom rocks formed an element which he thought no calculation could reach. If the working was carried out in a mass of coal of infinite extent, then one might be disposed to consider the resistance to the circumference of the semicircular or shallow cylinder and the sphere which would have to be separated if the force were applied in a mass; but inasmuch as the layer was confined between sides of rock, and that rock was pressed by a superincumbent weight of untold amount, the question was incapable of solution. On general grounds he believed it would be impossible for the Institution to arrive at any definite conclusion with regard to the best machine. The machines of Mr. Chubb and of Mr. Jones

were similar in principle, and were both no doubt powerful though limited in range of expansion; but, while such limited range was sufficient to separate the coal, he believed that the largest quantity of coal could be got with a minimum expenditure of force, because all the force of that short range was directly applied. It was, however, necessary that the coal should be sufficiently hard to allow of a perfectly cylindrical hole being drilled or bored, and that it should not yield more than the length of the stroke of the pistons. Mr. Bidder's machine, on the other hand, was capable of greater range, and by it greater force could be brought to bear upon one point. It seemed also to have the advantage that a smaller hole sufficed for its action; but, on the other hand, that hole must be deeper than was necessary in the case of Mr. Chubb's machine. He subscribed to the objection urged by Mr. Mallet, that a proportion, not easily ascertained, of the force expended must be lost by pressing the front of the wedge against the mass of dead coal. The wedges pressed not against the coal that was going to be loosened, but against the dead mass of coal further on; and it was a question, which would puzzle a mathematician to determine, what proportion of force was expended in compressing the coal, and what proportion in cracking it away from its position. With Mr. Bidder's machine the loss of a portion of the pressure by the compression of the coal suggested to Mr. Siemens a modification which was this:—where coal was naturally tender, and where it was advisable to work it in comparatively thin layers, there might be applied a machine composed of three strong steel bars, arranged like a pair of scissors, with a hydraulic ram driving at the ends into gudgeons, so as to press out the ends of the scissors; the ends of the bars being provided with little surface-plates to distribute the pressure over a certain extent of surface. Such a machine, in coal sufficiently tender, would work rapidly, because with one piston in operation a range of at least 9 inches could be obtained, and the fissure in that case would be in aid of the separation of the mass.

Mr. Grissell suggested, with reference to the machine of Mr. Grafton Jones, that if a centre-bit point were placed on the end of the ram it might be used first as an auger, and afterwards as a ram when so screwed into the coal. It would clear itself from the cut coal up the sides of the ram, and then the ram would thrust out the pistons. He directed attention to the explosive substance lately introduced by Mr. Nobel—dynamite, or nitro-glycerine mixed with sand—which could be passed into a hole $\frac{3}{4}$ of an inch in diameter, and which evolved in exploding more force than powder, without giving off flame, gas, or smoke. In all respects he believed it was superior to powder for blasting operations.

Mr. Bidder, Past President, confessed that he approached the subject under discussion with strong personal feelings. As a coal-owner he was deeply interested in any apparatus, or system, which would tend to prevent the present sacrifice of human life, and at the same time effect economy in the working of coal—whether in the labour necessary for bringing it 'to bank,' or in 'getting' the coal in such a manner as to avoid the breaking up of the valuable large coal into small and 'slack.' He was also interested in the success of his young relative, the inventor of one of the machines. He was desirous of mentioning the active part taken in this invention by his friend Mr. Jones, who had brought to bear upon it the same practical skill that he had done in the case of another invention of great merit—Mr. Edwin Clark's Hydraulic-lift Graving Dock,—which had been raised by Mr. Jones' exertions from a state of pecuniary loss to a condition of prosperity.

Mr. Bidder had heard with dismay the subject of the use of gunpowder in coal-getting treated with a levity for which he was not prepared. When it was stated that out of the 1,484 persons killed in one year in mining operations, not more than 34 deaths were attributable to gunpowder, he repeated, that he received such an observation with dismay.

On the subject of these inventions, it must be recorded that, whatever might be their several merits, they had been chiefly induced and encouraged by his partner, Mr. G. Elliot, M.P., M. Inst. C.E., whose large experience need not be recalled. For years past Mr. Elliot's tranquillity had been much invaded, by a constant dread of the results of the use of gunpowder in mines subject to fiery gas, and he had repeatedly pressed the Government to offer a premium to stimulate inventors to apply their minds to the subject. Notwithstanding the statement which had been made, it was generally admitted, by mining engineers of experience, that the employment of gunpowder in coal-mining did occasion serious apprehension on the part of all practical men. Mr. Bidder knew that it affected, to a great extent, the profitable results of coal-mines. He did not pretend to be a practical coal-miner, but he happened to know a good deal about the financial results of coal-mining, and that breaking up the coal into small fragments occasioned considerable loss. Therefore anything that tended to mitigate that result was of importance in a pecuniary point of view; but he regarded that as of secondary importance, as compared to the question of the saving of human life.

The first he heard of these inventions was from being consulted by Mr. Chubb, who had been instigated by Mr. Elliot; and he believed the original idea was the direct application of water. Mr. Bidder expressed the opinion that, as there existed so many fissures in coal, the direct application of water would be impracticable; and

the result had shown this view to be correct. Alluding to the machine brought forward by Mr. Chubb, though he did not think the invention was entirely successful, yet the inventor was entitled to credit for having addressed his mind to this great practical problem. Long before the attention of his relative had been turned to this subject, Mr. Chubb had been considering it, and, having prepared a machine, made application to Mr. Craig, the Manager of the Harecastle Colliery, for permission to make experiments with it there. That permission was readily accorded, and, if his recollection were correct, Mr. Chubb then stated that the machine had been successfully applied in South Wales. Of course success in one case did not imply equal success in all other cases; and after a trial extending over three weeks, during which the inventor was left entirely uncontrolled, and was allowed to work at his own discretion, the machine, then experimented with, was not successful, equally to the regret of the inventor and to that of the proprietors of the mine; and it was somewhat surprising now, as the machine was stated to have been successfully applied in South Wales, to find that, after modification, no application had been made to repeat the trials at Harecastle. But if the machine was successful anywhere, that omission was not material. It would have been more conclusive to have had a report from the colliery manager, with regard to the experiments with this machine in South Wales, after the manner of that which had been made upon the trial of his nephew's machine at Harecastle.

There was one point which Mr. Chubb would probably be able to explain. It was stated that the pressure in his hydraulic machine was 12 tons to the inch. How that pressure was to be attained, and what sort of lever was to be used, had not been stated; but whatever might be the pressure in one case, it was equally obtainable in the other. Apart, however, from that, he would mention that three leading principles had been laid down by Mr. Elliot as the main objects to be sought for, in any machine for breaking down coal. First, that the apparatus should be so portable that it could be easily carried about the workings of a coal-mine; secondly, that it should be capable of being applied by the men who were ordinarily engaged in working the mine; and, thirdly, that there should be freedom from liability to accident. It was all very well to assume that the operations of coal getting were performed in a gallery of perfect form; but the workings of a coal-mine were the most dislocated places that could be conceived, and were such as men could not work in with accuracy. The machine then, as before stated, required to be portable, easily applicable, and free from the liability to accidents from the casualties to which these workings were subject. Any machine which, after the pressure was applied, failed to bring down the coal, was obliged to be withdrawn to

insert 'liners,' and to perform other operations, could not be considered perfect. It must be borne in mind that the first operation of the wedges was to dislocate the coal; and the subsequent application was to remove the coal to a sufficient extent to enable it to be worked out; and as to loss of power, the question was whether the power applied was economical and sufficient, and whether the cost of getting coal by these means was within the limits of that which was the result of the application of gunpowder.

It appeared, from the best information that could be obtained, that the cost of labour, connected with the application of this machine and working with gunpowder, was nearly the same. That was to say, the cost of the extra time required to drill the holes and break down the coal was as nearly as possible the same as in the application of gunpowder: in other words, though it took more time to make the hole, there was a saving of the time necessary to clear the working of the vapours evolved by the explosion of the gunpowder.

With regard to undercutting, in many instances that process could not be employed, and he believed that was the case at Harecastle. He did not mean to give any direct preference to any of these machines; but he was puzzled to know in what respect Mr. Chubb's machine differed in principle from that of Mr. Grafton Jones. If there were any success in the one, it might be expected from the use of the other; and the inventors must settle how the merit was to be divided, and also the emolument, which he hoped would be eventually derived from it; but it was surprising it had hitherto escaped notice, that these two machines were essentially the same in principle. It was true Mr. Chubb suggested a mode by which the insufficient expansion was supplemented by 'liners,' but that would appear to be an inefficient application. In all other respects the machines were similar.

There had been read to the meeting, during the course of the discussion, a letter from the "South Staffordshire and East Worcestershire Institute of Mining Engineers," which was composed of men who possessed an amount of practical information on the subject of coal-mining far beyond what The Institution of Civil Engineers could command. That Institute had clearly arrived at the opinion, that a machine for breaking down coal was desirable, and also that a particular machine had accomplished the object to a certain extent; but of course it could not be said that any other machine would not do it as well, or better. It struck Mr. Bidder this was a happy commencement of the co-operation between the members of The Institution of Civil Engineers and the members of an Institute of Mining Engineers. The line between them was difficult to draw; but no doubt the

multifarious experience and aptitude of the members of The Institution of Civil Engineers might be usefully applied to mining in its various phases. He would instance the subject of ventilation, to which attention should be directed, and in which great improvements might be made. The old-fashioned plan, which was almost universally employed, was to have a large fire in the upcast shaft. Now he need not say that the furnace in the upcast shaft was an element of danger. It produced a low barometer; it exhausted the air, reduced the pressure, and thus destroyed the balance between the atmosphere in the workings and the tension of the gases which existed in the fissures of the coal. No doubt could be entertained, that it had a tendency to induce 'blowers' of gas, and to cause explosions. Lately a fan had been introduced, with the view of blowing the air through the workings. That must increase the pressure instead of lowering it, and create an artificially high barometer; and in addition, it materially cooled the mine, by the expansion of the atmosphere after it had been condensed in the workings. He made these few general remarks, because he could not help expressing satisfaction at seeing that the rising generation of engineers were directing attention to a practical problem, which had a marked effect upon the manufactured products of the day; and he preferred to see engineering talent devoted to the pure practice of the profession, rather than to modern financing operations.

Mr. R. Price Williams, having been practically acquainted with mining operations from an early age, could confirm what had been said by Mr. Lupton, as to the necessity of the use of powder in coal-mining operations. He was well acquainted with the Rhondda Valley coal district, and there, as in the Derbyshire coal district, powder was never required for breaking down the coal; in fact, its use was strictly prohibited. He was anxious the erroneous impression that these machines, useful as they might prove to be in their way, would supersede the further employment of powder in coal-mining should not go forth; the fact being that the mere breaking down of the coal, for which these machines were specially and solely designed, was, after all, one only of the many operations connected with that pursuit. No reference had been made in either of the Papers to more difficult mining operations, such as driving the headings and airways, which necessitated the cutting away of large quantities of hard rock, so as to obtain sufficient headway for the passage of men and horses, operations for which these machines were in no way calculated, and where the employment of powder was at present indispensable. The thickness of the upper coal measures in the Rhondda Valley varied from 2 feet 6 inches to 3 feet. In driving the headings and in working the coal it would be necessary to cut, either from the top or the bottom, or from both

occasionally, sufficient headway to allow of the passage of horses and men. These headings in the Rhondda district were on an average 8 feet wide by 6 feet high. The thickness of the lower, or steam coal measures, usually varied from 5 feet 6 inches to 6 feet, and sometimes what was termed the irregular 9 feet varied from 8 feet to 10 feet in thickness. It was therefore evident that, even with this thicker description of coal, there must remain a considerable amount of top and bottom to be cut away. He had recently ascertained that the weight of powder used in blasting the rock in the Rhondda Collieries amounted on an average to 1 lb. per yard of road cut, and that in a colliery such as he now referred to, producing 200 tons of coal a day, about fifteen shots a day would be necessary in driving these roadways. The quantity of rubbish to each ton of coal was usually about 6 tons in the headings and 5 tons in the stalls, the whole of which was left underground in working on the pillar and stall system. The proportion of small coal to round was about one-fifth in Nos. 2 and 3 Rhondda coal, and about one-twelfth in the thicker or steam coal measures. Naked lights were used in working the former, but not in the steam coal measures. The blasting was in both cases done under the supervision of men specially appointed for the purpose, and usually when the men were at work. In these collieries the coal was got in the way described by Mr. Lupton. In the Rhondda upper measures the coal was holed and cut, and came readily down, squeezed out, in fact, by the enormous pressure of the superincumbent strata. If a machine could be devised that would not merely break down the coal, but grapple with the hard rock itself and cut the 'top' and 'bottom,' so as to give sufficient headway, it would greatly conduce to the safety of mining operations; until then powder would still be necessary in coal-mining; and seeing how much its continued use affected the life, safety, and health of the miner, he thought the attention of engineers could not be directed to a better object than devising some practical method for dispensing with it entirely.

Mr. G. H. Phipps, whilst agreeing with Mr. Mallet as to the existence of some angle of wedge theoretically more appropriate than any other angle, was inclined to think that enough was done if Mr. Bidder's instrument was shown to possess sufficient power to detach the coal. This was no case for nicely balancing the quantity of mechanical power required to produce the effect in different instruments, as the actual operation of working the pump was always within the power of the workmen on the spot. He thought the arrangement of the wedges in the instrument well adapted to their intended use, as the more acute wedge which first came into action was calculated to exert the high power required in establishing a slight fissure in the coal; while the wedges subsequently

employed did not require to exert so much force laterally, their office being only to push out the mass already detached by the first wedge.

Mr. T. Dyne Steel held that firing shots in fiery pits, where locked lamps were the rigid rule, was an anomalous state of things that ought to be done away with, at once, and for ever. The hydraulic machines of Mr. Grafton Jones, Mr. Chubb, and others, were really practical machines, and he thought they would, in a great measure, if not entirely, supersede coal-cutting, or holing, machines. If the holes for the 'breaker' were drilled in the seam of coal at right angles to the face, holing in the coal must first be done, either by colliers or by a coal-cutting machine, before the 'breaker' could be used; but if the holes were drilled diagonally, he saw no reason why holing should not then be dispensed with altogether, under favourable circumstances.

The centre of the seam being broken out by the machine, the top and bottom part could be readily got with the pick. In order to carry out this to advantage, it would be necessary, first, to cut 3 feet or 4 feet deep at the right or left of the stall nearest the rib as might be most convenient, and then to insert the breaking machine diagonally, at such a distance from the cut as experience, or the nature of the seam to be operated upon, might determine. The holes following would be drilled in like manner, and the machine used from hole to hole along the face of the stall. With regard to the breaking-down machines, those seen by him were efficient and answered the purpose well. He had little faith in the success of coal-cutting, or holing, machines, except under very favourable circumstances. No machine had yet been produced that could take the place of the collier's mandrel in all situations.

Mr. J. Coe, of the Biddulph Valley Coal and Iron Works, observed, through the Secretary, that, many years ago, he had enlarged the shaft of a coal-mine by taper wedges, when naked lights could not be used. In this case, the wedges answered very well, and the cost of enlarging the pit was not much more than if it had been done by blasting. Immediately after the explosions at the Oaks and Talke-o'-th'-Hill Collieries, he tried the application of the wedges on the hard coal of the district, where a great deal of powder had been required for blasting. He holed the coal in the usual way, and drilled holes as if for powder, working them 3 inches in diameter. He then inserted two wedges in each hole, with their thick ends inwards, and drove home the main wedge. The wedges were from 1 foot to 4 feet in length, as the case required. The backs of the minor wedges were round, and the faces slightly concave. The main wedge was slightly convex on both sides. From the results of his experiments, he

was quite certain that powder might be dispensed with in all dangerous places, if mining engineers would take the matter up in a determined manner. He thought that if Mr. Bidder could apply pressure and concussion at the same time, he would accomplish all that was wanted, but that concussion must be applied to his wedge.

Mr. Chubb, in reply upon the discussion, observed that his Paper had been prepared simply with a view to put himself in a proper position before the Institution, in consequence of the observations which had been made upon his apparatus in the Paper of Mr. Bidder, jun. Some friends, who had seen his machine at work in Wales, came up on purpose to take part in the discussion, but they had, unfortunately, not been able to obtain an opportunity of doing so. He would, therefore, refer to a few letters which he had received on the subject. Mr. W. T. Lewis (M. Inst. C.E.), who was the agent for the Marquis of Bute, wrote as follows:—

"Having been present at the trials at Fforchaman Colliery, I have great pleasure in endorsing all Mr. Richard Bedlington has said respecting the advantages to be derived from the adoption of your machine in the working of our Welsh coals, more especially the steam coals, which are exceedingly hard and highly dangerous to use gunpowder in. Having since then witnessed trials in the two-feet-nine seam, which is the strongest coal in our district, and which cleaves to the top and bottom, I have no hesitation in saying that it has only to be known to be generally adopted, both as a means of doing away with accidents from blasting, and also of reducing the cost of working very materially."

He would next refer to the failure of the machine at Harecastle Colliery. It was taken there only a short time after it had been brought out, and the experiment was made at the request of Mr. Elliot and Mr. Craig. He asked Mr. Craig a month previously to have a hole bored in the coal $4\frac{1}{2}$ inches diameter to a depth of 4 feet. Mr. Craig wrote in reply, that the hole should be made perfectly straight and true, and that if wished it could be 6 inches diameter. He went down with the machine, and found the hole, which had been made by a jumping tool instead of being bored out, neither straight nor round, and twice the size at the centre that it was at either end; consequently, the machine, being adapted for a round and true hole, had to be expanded in the first instance to fit it, and ultimately was bent. The expansion of the apparatus was $2\frac{1}{4}$ inches. This he had found sufficient for splitting the coal he had up to the present time had to do with; though this limited expansion might not answer for a wedge. In the case of a wedge there were two points bearing on the surface, and there must be a large expansion, in consequence of the small area brought to bear upon the coal. In his machine the area was on one side 75 square inches, and on the other upwards of 100 square inches. And if the expansion of $2\frac{1}{4}$ inches

were not sufficient, it would be easy to introduce a liner between the plungers and the cover plate. The plungers could be brought back by opening a small valve to let the water off, and shaking the apparatus in the hole; then the liner could be put in. The coal did not spring back to the full extent of the expansion of the machine. Where the expansion had been 2 inches, the coal did not spring back more than about $\frac{3}{4}$ of an inch. The liner was a piece of metal sufficiently small to pass between the two sides or cheeks of the cover plate; the end was made wedge-shaped to avoid catching against the plungers.

The drill he had exhibited, had, up to that time, bored about fifty holes in both hard and soft coal, and it had also drilled through 'brass,' or copper pyrites as he supposed it to be. It was worked by one man, and the time occupied in drilling each hole, was, on an average, from twelve minutes to fifteen minutes, and allowing from three minutes to five minutes for placing the drill in position, on the outside not more than twenty minutes would be occupied in each case. When he was at Harecastle two hours were required to drill a hole, and Mr. Craig objected to the machine because it was proposed to use a drill instead of the ordinary jumper, saying that it would be a mistake to introduce a new form of labour among mining men. The only difference, however, would be, that one man would have to turn a wheel instead of two men having to use a large punch as it was called; and the drill would make a perfectly true hole in ten minutes in the coal, whereas the punching took at least two hours for a hole $4\frac{1}{2}$ inches diameter. This drill was worked in the presence of Mr. R. Bedlington, President of the South Wales Institute of Mining Engineers, who had written to him as follows:—

"Having heard that your machine was doing its work very well, I went to Fforchaman Colliery, near Aberdare, to see it at work.

"Several mining engineers were present at the trials. Four holes were bored.

"The 1st hole—Boring occupied	.	$13\frac{1}{3}$ minutes.
Fixing the machine,		not timed.
Pumping.	.	ditto.
"2nd hole—Boring	.	14 minutes.
Fixing	.	6 „
Pumping.	.	5 „
Total	.	25 „
"3rd hole—Boring	.	$12\frac{1}{3}$ minutes.
Fixing	.	$5\frac{1}{2}$ „
Pumping.	.	3 „
Total	.	21 „

"4th hole—Boring	. . .	$13\frac{1}{2}$ minutes.
Fixing	. . .	$15\frac{1}{2}$,,
Pumping	. . .	$6\frac{1}{2}$,,
Total	.	$35\frac{1}{2}$,,

"The total time occupied in the trials was two hours, and about 36 tons of coal, I am informed, were loosened, so as to enable the colliers by pick and mandrel to extract the coal.

"Compared with the amount of small coal made in holing, the small made by the bore is less. Less small coal is also made by the machine in severing the coals than by powder. This is an important point in favour of the machine in steam coal collieries.

"The necessity of using powder in the extraction of coal is by your machine done away with. I should be glad to learn that the machine could also be applied to the working of strong ground, so as to enable us to rip top, and cut bottom, in our workings without using powder.

"I believe that your machine will effect a saving in the cost of cutting coal; and to the extent of the disuse of powder, will be a step towards greater safety.

"Another important point is, that the coal can be worked more rapidly along a face of work, and therefore a much larger amount of coal can be extracted from a given area within a certain time."

Mr. Woodhouse, Mr. Warington Smyth, and Mr. Craig, seemed to be of opinion that it would be impossible to get the coal out by this machine without first either holing, cutting, or nicking it. In all the trials he had made, the coal had not been prepared in any way before he commenced drilling, either by holing, cutting, or nicking, and in all those trials with his machine, the coal had been thrown out so that it could be rapidly removed. The chief expense and loss in the ordinary operation of getting coal was the undercutting or overcutting, as the case might be; but with his machine none was required, in proof of which he submitted a report from the managers and agents of the Powell Duffryn Steam Coal Company upon the action of his machine in the Aberaman, the Middle Duffryn, the Fforchaman, and the Lower Duffryn collieries:—

"*Report of the Managers and Agents of the Powell Duffryn Steam Coal Company, Limited, upon the action of Chubb's Patent Coal Getter.*

"We, the undersigned, have witnessed the following experiments; viz., Aberaman Colliery.—'Four-feet seam.' This seam is six feet thick; strong coal, and powder is used. The experiment was tried in a twelve-yard stall, double road; the left-hand rib was cut two and a half yards in, under the top coal, which is one foot thick. The first hole was drilled six feet from the cut, to a depth of three feet six inches, and the apparatus forced off about three tons. The second was drilled in six feet to the right of the last hole, the same distance in, and because the slips ran diagonally across the stall, this hole reached into the second slip, and forced off about eleven tons. There was in this fall a block of solid coal of three tons weight. The third hole was drilled six feet to the right of

the second hole, and forced off about four tons, making a total of eighteen tons in one hour and three minutes. * * * * *

"The second experiment was tried at Middle Duffryn Colliery, in the 'Six-feet seam.' The coal is exceedingly hard, and sticks fast at both top and bottom. The hardest place in the pit was chosen in order to test the machine thoroughly. Only one hole was tried, and it was drilled in a long wall face without either cutting or holing, and about four tons of coal was forced off in twenty minutes. This experiment was made the day previous to the meeting of the South Wales Institute of Engineers, and as the machine had to be sent off that day, time did not permit any further trials. * * * * * * *

"The third experiment was tried at Fforchaman Colliery, in 'Six-feet seam,' being three feet two inches in thickness, and sticks to bottom. A place was selected in the long wall face, and a layer of 'brass' three inches thick runs through that part. No preparation by holing or cutting was made. Five holes were drilled along the face, the machine applied to each, and the result was, that the whole of the face for a distance of forty-eight yards was forced off, being equal to about forty-five tons, in the space of three hours and ten minutes. * * * *

"The fourth experiment was made at the Lower Duffryn Colliery, in the 'Nine-feet seam,' where it is impossible to work without powder, as the coal sticks hard to the bottom. The first trial was in a ten-yard single stall, the coal being six feet in thickness, the top coal left up. The hole was drilled in the middle of the stall, over a shot which was ready for firing. No cutting or holing was made. The machine forced off about five tons. The next hole was drilled close to the right-hand rib in the same stall, and about three tons was forced off. The third hole was in the second stall, and so placed that it forced off the face of the stall, equal to about ten tons. The fourth and fifth holes together, in another stall, forced out about seven tons. On account of the danger of using gunpowder in this seam and the impossibility of working it hitherto without, it has been decided to work it in future entirely with the coal getter, and it will be adopted forthwith. * * * * *

"A fifth experiment was made at the Fforchaman Colliery, in the same long wall as the former one. No preparation was made either by cutting or holing. Three holes were drilled, and the machine in this case forced off 36 tons in two hours. * * * * * *

"From the foregoing experiments we are of opinion the 'Coal Getter' will remove to a great extent explosions of gas, which often arise from the use of powder; it does not shake the top, thereby removing frequent causes of accidents; it works out the coal in better condition, making it bear transit better than when worked by powder; requires no holing, and therefore makes little or no small coal; and, lastly, it works out the coal in less time, and therefore does not require so large a working face—thus making ventilation more efficient; and, in conclusion we would say, that wherever gunpowder is used in getting coal, either in this district or elsewhere, this instrument may be applied with great success.

"Signed—

George Wilkinson, Manager, Duffryn Collieries.
Thomas Burn, Manager, Cwm Newl Fforchaman and Aberaman Collieries.
Frederick Wilmer, Mining Engineer.
George Wilkinson, Mining Engineer.
John Snape, Mechanical Engineer."

A question had been raised as to the possibility of getting 12 tons

pressure to the square inch with the pump he had applied to the apparatus. The lever was divided in the proportion of 30 to 1, and the area of the plunger of the pump was 0·44 square inch; from this it would be found that a force of 394 lbs. at the long end of that lever would give a pressure of 12 tons on the inch. The ratio of 30 to 1 was taken on the assumption that the hands of two men occupied a space of 18 inches, the effective length of the longer arm being diminished by 9 inches, as calculated from the centre of application of the force.

Remarks had been made that his machine and that of Mr. Grafton Jones were essentially the same, and no doubt there was much truth in the remarks; but there was this important point with respect to the time of their introduction, the fact being that his was patented in March, 1868, while that of Mr. Jones was not patented till the following October, and he might add, that his specification described exactly the apparatus exhibited by Mr. Jones. Mr. Jones had, however, previously invented another apparatus, which led to the remark in his Paper about giving up the idea of wedges altogether, and seeking for some other power to be used with more effect. Mr. Jones in 1864 patented a wedging apparatus, and had communicated to him the amount of success and failure that attended it. It was Mr. Jones' opinion that a wedging apparatus would be of no use, as the wedges bent the side plates every time they were used, and as the wedges were cut up and spoilt very rapidly. Besides, when the coal was forced apart with the wedging apparatus, the apparatus could not be removed from the hole till the whole of the coal was brought down; so that there must be a separate wedging apparatus for every block of coal brought down in different places at the same time. In conclusion, he remarked that he should be amply repaid if hereafter his machine, or any other brought out in consequence of the discussion, had been the means of lessening the risks of working coal.

Mr. S. P. Bidder, jun., in replying upon the discussion, thought it was unnecessary to say anything with regard to the various modes of working, as the special object of the discussion was to determine the most suitable machine to take the place of powder, and capable of being worked in any description of coal. He considered that his machine had certain advantages over the others which had been brought forward. In the first place it was extremely portable. The press was independent of the straps and wedges; and instead of each gang of colliers requiring a complete machine, a strap and three or four wedges sufficed. The machine could be constructed to enter a hole 2 inches in diameter, and in no case did it exceed 3 inches in diameter, as the boring of a hole above that size was attended with considerable difficulty.

He thought Mr. Chubb would find it troublesome, to say the least of it, to transport a drilling-machine of the necessary size through the airways and passages of a mine; besides which, drilling was a class of labour to which the miners were not accustomed. The large amount of expansion in his machine made it suitable for any description of coal. The expansion part of the apparatus acted over the full area of the bore-hole, and the wedges, being made of the best steel, were almost indestructible. The power, once applied, was not removed till the coal was brought down: it was equivalent to 15 tons multiplied five times by the wedges, giving 75 tons outward pressure of the expanding box. He was of opinion that the power necessary to break down a body of coal by his machine, according to the present system of working, would never exceed 100 tons. He could not admit that the use of powder was free from danger when superior workmen were selected to fire the shots; and although so few accidents were attributed to explosions, yet the verdict of many a coroner's inquest—that from the nature of the accident the precise cause of death was wrapped in mystery—was a convincing proof that the majority were caused by the use of powder. Then, again, as to undercutting being sufficient to bring down coal by the force of its own gravity, that could only be when the cleavage was exceptionally distinct, which did not apply to one-tenth of the coal so undercut. Many seams were overcut, owing to a bad parting between the coal and the floor, or there might be soft dirt at the top. At Harecastle, where coal fetched a higher price than in any other part of the country, and where the pit price of coal was always high, he found that while round coal was worth 7*s.* 6*d.* or 8*s.* per ton, the price of the slack sold for making coke never realized more than 4*s.* to 4*s.* 6*d.* per ton. The direct saving to be gained by the use of the machine could only be stated in general terms: one great element, however, consisted in the entire freedom from accident from blasting. Mr. Woodhouse justly remarked that there was such a variety of coal, that in one case the advantage might be one shilling and in another a farthing per ton. Mr. Chubb seemed to think that the wedges were liable to be damaged and destroyed, but they were made of the best steel and tempered, and endured the trials at Harecastle without a scratch; nor were they bent more than $\frac{1}{16}$th of an inch after bringing down from 25 tons to 30 tons of coal. In the case of the pillar, shown in Plate 10, the test was more severe than the machine would ever be likely to undergo in practice. He apprehended that what was required was a machine capable of dealing with the worst conditions of coal, which he considered his machine had successfully accomplished at the Harecastle Collieries, where it was admitted by Mr. Chubb the coal was exceptionally tough and hard to work.

Mr. Gregory, President, said he was sure the members present appreciated the interesting discussion which had just been concluded; and, while thanking Mr. Bidder and Mr. Chubb for their Papers, were also obliged to other gentlemen who had given a description of their inventions for similar purposes. He would add his conviction that the members cordially welcomed the presence of their brother engineers, whose attention was more particularly directed to the means of the economical and safe getting of coal, so important to the interests and the greatness of this country; and were pleased to receive into the Institution more of those who had had large experience in this useful branch of the profession. He hoped the gentlemen whose inventions were under consideration would avail themselves of the facilities so kindly offered by Mr. Woodhouse for trying their machines, under various conditions, in the mines under his direction.

Different machines, or modifications of machines, might be applicable to different circumstances: one might be applicable to hard coal, and another mechanical arrangement might be better suited to soft coal. Some coal was of such a hard nature that a small amount of expansion would break out the mass from the seam; while coal of a soft and yielding nature would require a large amount of motion in a part of the apparatus. Again, the position and the cleavage of the coal, and the thickness and inclination of the seams, and the mode of working, would all affect the nature of the apparatus to be used. It would have been interesting to have had before them, when considering this subject, more information with regard to the machines used for cutting and grooving coal; and it still remained to be decided, how far the use of machines for breaking down the coal would supersede the necessity of undercutting or holing. These remarks naturally led to the conclusion, that no general rule could be laid down, and that the machines might have to be varied according to the duty they had to perform. Still, looking at the work to be done, it might be suggested that if the process could be effected by one instead of by a number of operations, there would be a saving as regards simplicity of working and economy of time and labour.

As the hydrostatic press was an important feature in some of the machinery which had been under consideration, and having had the honour, when an apprentice, to work he might almost say at the same bench which had been used by the celebrated Joseph Bramah, he hoped it would not be considered irrelevant if he laid on the table a letter which he had received from Mr. Mallet, containing photographic copies of a letter from Mr. Bramah to Mr. Mallet's maternal grandfather, and of the original drawing, supposed to be by Mr. Bramah himself, of the well-known lock. All who had studied the works of Joseph Bramah must have

been impressed with the great variety of his inventions, which ranged from the simplest and most common objects of daily use, to the most powerful and complicated machinery. The letter was dated 10th November, 1802, and it showed that Mr. Bramah at that time had designed a complete system for the transmission of power by means of hydraulic connection, and had anticipated the immense extent to which such a system might be carried. His words were as follows:—"I have also now applied it, with the most surprising effect, to every sort of crane for raising and lowering goods in and out of warehouses. So complete is the device that I will engage to erect a steam-engine in any part of Dublin, and from it convey motion and power to all the cranes on the quays and elsewhere, by which goods of any weight may be raised at one-third of the usual cost."

He thought that these documents deserved an honourable place in their archives, in remembrance of a man who had done more than most for the good of his fellow-men, by his profound mechanical ability.

ANNUAL GENERAL MEETING.

December 22, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

Messrs. C. Frewer, H. Hayter, T. Marr Johnson, T. M. Smith, and Joseph Taylor, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-President, and other Members and Associates of Council; and it was resolved that the ballot papers should be sent for examination, at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The list of members prepared for Council, together with the record of the attendances of the Members of Council, in Council and at the Ordinary General Meetings, was read, and the Ballot was declared open.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. J. D. Baldry and C. E. Hollingsworth, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear statement they have laid before the Meeting; and that Messrs. C. E. Hollingsworth and Charles Hawksley be requested to undertake the office of Auditors for the ensuing year.

Mr. Baldry returned thanks.

The Telford and Watt Medals, and the Telford and Manby Premiums of Books, which had been awarded, were presented.

Resolved,—That the cordial thanks of the Institution be presented to George Parker Bidder, Esq. (Past-President), and to George Robert Stephenson, Esq. (Member of Council), for their very liberal contributions to the Institution in aid of the New Building, as recorded in the Annual Report.

Mr. Stephenson returned thanks.

Resolved,—That the Council be authorized to grant the use of the Rooms of the Institution when such use may be thought expedient.

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Hawksley, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Gregory, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Gregory, President, returned thanks.

Resolved,—That the special thanks of the Meeting be tendered to Mr. T. H. Wyatt, the Architect, for the skill displayed in the design of the New Building of the Institution.

Resolved,—That the thanks of the members be presented to Messrs. Holland and Hannen, the builders, for the satisfactory manner in which they have performed their contract.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

CHARLES HUTTON GREGORY.

Vice-Presidents.

Joseph Cubitt.	Thomas Hawksley.
Thomas Elliot Harrison.	Charles Vignoles, F.R.S.

Other Members of Council.

Members.

James Abernethy.	Frederick Joseph Bramwell.
William Henry Barlow, F.R.S.	James Brunlees.
John Frederic Bateman, F.R.S.	George Willoughby Hemans.
Joseph William Bazalgette.	John Murray.
Nathaniel Beardmore.	George Robert Stephenson.

Associates.

Major-General Sir W. T. Denison, K.C.B., F.R.S.	Frederick Ransome.

Resolved,—That the best thanks of the Institution be given to the Secretaries, not only for their usual valued services, but

especially for the watchful attention they have given to the interests of the Institution in the arrangements and construction of the New Building.

Resolved,—That the thanks of the Meeting be given to Messrs. Frewer, Hayter, Johnson, Smith, and Taylor, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

ANNUAL REPORT.

Session 1868–69.

The Council to whom was confided at the last Annual General Meeting the direction and management of the affairs of the Institution beg leave to submit the following Report upon its present state and condition.

During the past session there were twenty-three Ordinary General Meetings, when Papers were read and discussions took place on various professional subjects. These included the benefits and expedients of Irrigation in India, Spain, and other warm climates, and on the proper construction of Irrigating Canals; the manufacture and wear of Railway Bars; the relation of the Fresh-water Floods of Rivers to the areas and physical features of their basins; on Floods in the Nerbudda Valley, with remarks on Monsoon Floods in India generally; on the Victoria Bridge, on the line of the Victoria Station and Pimlico Railway; on New Railways at Battersea, and the widening of the Victoria Bridge; the City Terminus Extension of the Charing Cross Railway, embracing a description of the Cannon Street Bridge and Station; the Durability of Materials; the Supporting Power of Piles, and on the Pneumatic Process for sinking Iron Columns, as practised in America; and the Experimental Determination of the Strains on the Suspension Ties of a Bow-string Girder.

Although the topics thus dealt with have been comparatively limited in number, yet, it is believed, they may be fairly regarded as representing some of the principal problems now engaging the attention of engineers. There is, for instance, probably no question of greater national importance, having regard to the interests and welfare of so many of the Queen's subjects, than that of Irrigation. Hitherto the records of the Institution have been a blank upon this branch of engineering practice; while treatises on the subject, at least in the English language, have previously been almost entirely wanting.

For these communications the following Telford and Watt Medals, and Telford and Manby Premiums of Books, have been awarded:—

1. A Telford Medal, and a Telford Premium, in Books, to George Higgin, M. Inst. C.E., for his Paper "Irrigation in Spain, chiefly in reference to the Construction of the Henares and the Esla Canals in that country."
2. A Telford Medal, and a Telford Premium, in Books, to Christer Peter Sandberg, Assoc. Inst. C.E., for his Paper "On the Manufacture and Wear of Rails."
3. A Telford Medal, and a Telford Premium, in Books, to Lieut.-Colonel Peter Pierce Lyons O'Connell, R.E., Assoc. Inst. C.E., for his Paper "On the Relation of the Fresh Water Floods of Rivers to the Areas and Physical Features of their Basins."
4. A Telford Medal, and a Telford Premium, in Books, to William Wilson, M. Inst. C.E., for his "Description of the Victoria Bridge, on the line of the Victoria Station and Pimlico Railway."
5. A Telford Medal, and a Telford Premium, in Books, to Charles Douglas Fox, M. Inst. C.E., for his Paper "On New Railways at Battersea; with the Widening of the Victoria Bridge and Approaches to the Victoria Station."
6. A Telford Medal, and a Telford Premium, in Books, to John Wolfe Barry, M. Inst. C.E., for his Paper "On the City Terminus Extension of the Charing Cross Railway."

*7. A Watt Medal to Edwin Clark, M. Inst. C.E., for his Paper "On Engineering Philosophy; the Durability of Materials."

8. A Telford Medal to William Jarvis McAlpine, M. Inst. C.E., for his Paper "On the Supporting Power of Piles; and on the Pneumatic Process for sinking Iron Columns, as practised in America."
9. A Telford Premium, in Books, to Thomas Login, M. Inst. C.E., for his Paper "On the Benefits of Irrigation in India; and on the Proper Construction of Irrigating Canals."
10. A Telford Premium, in Books, to Allan Wilson, M. Inst. C.E., for his Paper "On Irrigation in India."
11. A Telford Premium, in Books, to Wilfrid Airy, Assoc. Inst. C.E., for his Paper "On the Experimental Determination of the Strains on the Suspension Ties of a Bowstring Girder."
12. The Manby Premium, in Books, to Andrew Cassels Howden, Assoc. Inst. C.E., for his Paper "On Floods in the Nerbudda Valley; with Remarks on Monsoon Floods in India generally."

The record of the attendances at the Ordinary General Meetings during the past session shows that there were present on an

* Has previously received a Telford Medal.

average 244 each evening, the maximum number at any one meeting being 350, and the minimum 175. In the four preceding sessions the numbers attending each meeting were 155, 175, 192, and 208, respectively.

Immediately after their election, the Council proceeded to take into consideration the question of providing additional accommodation for carrying on the business of the Institution, remitted to a previous Council by the resolution of the adjourned Special General Meeting of Members and Associates held on the 26th day of June, 1866. The views they arrived at, after mature and careful deliberation, were very fully detailed in a Report presented to a Special General Meeting of Members and Associates on the 7th of April, 1868. At that meeting the recommendation of the Council, that the existing site of No. 25, Great George Street, with the addition of the back part of the adjacent house, No. 24, should be adopted, was approved; and authority was given to the Council to enter into arrangements for a lease of 99 years for each of these premises, reserving for the time the question of purchase, on terms which had been agreed upon, and to take the necessary steps to carry out the Architect's designs for the rebuilding.

As soon as this decision was arrived at, the negotiations were resumed with the owners of the two properties, and have been completed on the terms stated in the Report of the Council previously referred to: that is to say, in the case of No. 25, Great George Street, for £450 per annum for 99 years, with the option of purchase within ten years for £12,000; and in the case of the back part of No. 24, Great George Street, for £208. 13*s.* 4*d.* per annum for 99 years, with a like power of making it freehold for £4,161. 13*s.* 4*d.* It should be mentioned that the two sums last named are the net amounts which will have to be paid, after making allowance for the very liberal gifts of two of the owners, viz., the entire of Mr. G. R. Stephenson's interest of one-third, and £500 in diminution of Mr. Bidder's interest, also of one-third. Acting under the advice of the Solicitor to the Institution, these leases have been taken in the names of Messrs. James Abernethy, Joseph William Bazalgette, Frederick Joseph Bramwell, Charles Hutton Gregory, and George Willoughby Hemans. A Declaration of Trust has been prepared, that these gentlemen hold the property in trust for the Institution, to be exchanged for a Deed of Indemnity to be executed by the Corporation, holding them jointly and severally harmless from the covenants contained in the leases.

The Council meanwhile devoted themselves to maturing the details of the plans of the New Building, and the Architect received instructions to prepare the specifications and contract drawings for the works, with alternative conditions, one for their completion and delivery in five months, so as to be ready for the opening of the

present session, the other for their performance in eight months. It was determined to invite a limited competition for the execution of the works; and tenders were received from Messrs. William Cubitt and Co., Messrs. Holland and Hannen, Messrs. J. and C. l'Anson, Messrs. Piper and Wheeler, and Messrs. George Smith and Co. The tender of Messrs. Holland and Hannen, being the lowest, was accepted. That firm undertook to finish the building according to the Architect's designs in five months for a sum of £11,650, and in eight months for a sum of £11,100. The contract was based on the first-named alternative, as it was considered very desirable to obtain possession of the new premises, so as to admit of the meetings being resumed at the usual time. The Council congratulate you that this result has been achieved; and they think that great credit is due to the Architect, Mr. T. H. Wyatt, for his very able direction of the works, and to the Contractors, Messrs. Holland and Hannen, for the arrangements they made to ensure the due fulfilment of their contract, as well as for the substantial and satisfactory manner in which all the work has been carried out. Nor can the Council omit to notice their indebtedness to both the Secretaries of the Institution, for the additional and unwearied assistance rendered by them to all parties during the period of the reconstruction of the building.

It was expressly stated on the plans issued to the members, along with the Report of the Council before alluded to, that they were only intended to give a general idea of what was proposed, but were not to be binding in detail. Several important modifications were afterwards made—the principal being the addition of a Newspaper and Tea Room on the ground floor, by which the area of accommodation for the general use of the members has been doubled, and the introduction of a glazed corridor on the first floor level—a further valuable concession granted by the owners of No. 24, Great George Street—by which it has been possible to provide four public entrances to the meeting-room, instead of two only as originally contemplated.

Time did not admit of the whole of the accounts in connection with the New Building and its accessories being examined and settled prior to the close of the financial year of the Institution on the 30th of November, so as to be included in one Statement of Expenditure. The Council have, however, caused all the accounts to be collected, in order to put the members in possession of the fullest and most reliable information on this subject. They are thus enabled to state that, whereas the estimated outlay, including all contingent expenses of moving, furniture, &c., amounted to £16,810, they fully believe the actual cost, including some furniture still to be delivered, will not exceed £17,250.

To meet the liabilities thus incurred, the Council decided to

dispose of, in the first instance, the Building Fund, being the accumulations of fees received from Members and Associates on joining the Institution; next to realize the Unconditional Bequests; and lastly, to sell so much as might be required of the investments made from time to time out of surplus income. The first two sources will, of course, be entirely exhausted, but as far as the Council can judge, when every liability is discharged, stock will still remain in hand of the nominal value of about £3,000, to provide for future contingencies.

The Stephenson Bequest of £2,000, the Miller Bequest of £2,000, the Errington Bequest of £1,000, and the Locke Bequest of £2,000 will hereafter disappear from the accounts, but the names of these benefactors will be held in grateful remembrance as connected with the erection of the New Building.

A Notice has recently been served on the Institution, that application is intended to be made to Parliament in the ensuing session for an Act, under the title of "Public Offices Concentration (Acquisition of Lands)," to empower the Commissioner of Her Majesty's Works and Public Buildings to acquire the property held by the Institution. The Council have in reply to this notice intimated their dissent from the proposed undertaking.

Before concluding this section of the Report, it should be stated that, when it was thought possible the Institution might require the temporary use of some other premises in which to hold the Tuesday evening meetings, application was made to the President of the Royal Society and to the Chairman of the Council of the Society of Arts. In reply, an intimation was received from each of these Societies, expressing their readiness to grant the use of their Theatres to The Institution of Civil Engineers. The Council felt that they only anticipated your wishes, in tendering to both these bodies your cordial thanks, for the kind and courteous manner in which their request had been received and had been acquiesced in.

Allusion was made in the last Annual Report to a suggestion, that the Council should institute an inquiry as to the systems of Engineering Education (other than Military Engineering) in different countries, the cost to the Students and to the respective Governments, and the effect, or presumed effect, of such preparatory training upon the profession. Believing that this investigation would lead, at all events, to the collection of information, which could not fail to be useful to the younger members, the Council caused a circular letter to be addressed to numerous technical establishments and private individuals abroad and at home; and this letter was accompanied by a series of questions, of which the following is a copy, to serve as a basis, but not in any way to limit the scope of the investigation:—

HEADS OF INQUIRY

as to Systems of Engineering Education in different Countries.

"The general system of Engineering Education (exclusive of Military Engineering).

"The presence or absence of Government support, and its nature if given.

"The Courses of Study and Examinations, if any, required before entering the profession.

"A list of the principal establishments for engineering education, with programmes of the courses of study pursued at each place, and details of the systems of teaching and of the whole *modus operandi* of communicating instruction. Also a Catalogue of the Text Books employed.

"The nature of the Diplomas, or Certificates granted, if any.

"Whether the plan of serving a regular pupilage to a practising Engineer, as in England, prevails; and if so, the Fees paid by the Pupils, and the duration of such pupilage.

"The practice of the profession as to the assumption of the style and title of Civil Engineer, without any previous regular training, certificate, or diploma.

"The titles of any printed Reports or other documents, bearing on the subject of Engineering Education, which may be consulted with advantage."

This circular has been very fully and cordially responded to, and the result has been the receipt, quite recently, of a mass of materials, which yet remains to be arranged, and which will, it is hoped, be in due time presented to the Institution. The best thanks of the members have in all cases been tendered to our several correspondents, for the trouble they took in furnishing the information so collected.

While on this subject it should be recorded, that Mr. Joseph Whitworth, M. Inst. C.E., feeling the necessity for some form of endowment in favour of those intended to follow industrial and scientific pursuits, has made a princely gift to the nation. At the Ordinary General Meeting of the Institution on the 28th of April, 1868, the following communication from the Council was brought forward, was adopted by acclamation, and a copy ordered to be sent to Mr. Whitworth :—"Attention having been called to the foundation, in perpetuity, by Mr. Joseph Whitworth, M. Inst. C.E., of Thirty Scholarships, of the annual value of £100 each, for the instruction of young men, natives of the United Kingdom, to be selected by open competition for their intelligence and proficiency in the theory and practice of mechanics and the cognate sciences, with a view to

the promotion of engineering and mechanical industry in this country, it was 'Resolved unanimously, that this Meeting desires to record, on its own behalf and on that of the members of all classes of The Institution of Civil Engineers, its grateful recognition of this act of munificence, and its high appreciation of the services which have thereby been rendered to the cause of technical education and national advancement, and of the advantages that may be expected to accrue, alike to the profession and to the community generally.'"

The Council, early in the last session, invited the Students to send in Papers, and informed them that when a sufficient number of approved communications were received, the Council would be prepared to grant the use of the Theatre of the Institution for Supplemental Meetings for the reading and discussion of Papers by the Students. At the same time it was intimated that by the will of the late Mr. Joseph Miller, M. Inst. C.E., the dividends and interest arising from the 'Miller Fund,' were applicable for Premiums for Papers submitted by the Students.

As the Students have not hitherto sent in any Papers, the Council have not been called upon to organize these Supplemental Meetings, which it was proposed should be presided over by Members of the Institution to be selected by the Council from time to time.

Since the last Annual Meeting, the Council Fund—hitherto carried to the credit of the general account—has been devoted to the purchase of books, for which a distinctive form of binding has been adopted. From this source, by the presentation of several series of American works, and by purchase in the ordinary way, the number of books added to the Library has proved larger than in any previous year. The injurious effect arising from a want of ventilation in the old library was, for some years past, shown by the rapid decay of the binding of the books in the upper shelves which constantly required repair. This evil does not exist in the new building; and the increased accommodation will allow of a better arrangement of the books under classes than heretofore. A Supplement to the Catalogue, issued in April, 1866, is completed in MS., with cross-references to the various subjects; and a classified MS. Catalogue is in course of preparation.

The tabular statement of the transfers, elections, deceases, and resignations of members of all classes during the years 1866-67 and 1867-68 (taking into consideration the names which have been erased from the Register) is as follows:—

Year.	Honorary Members.	Members.	Associates.	Graduates.	
1866–67.					
Transferred to Members	..	..	11	4	
„ „ Associates	..	..	..	2	
Elections	..	48	79	..	127−23=94
Deceases	2	14	10	..	33
Resignations	..	1	2	..	
Erased from Register	..	..	3	1	
1867–68.					
Transferred to Members	..	..	12	..	
Elections	..	45	105	..	150−34=116
Deceases	2	8	12	..	34
Resignations	..	1	10	..	
Erased from Register	..	..	1	..	
Members of all Classes on the Books, November 30th, 1868	16	637	896	..	1,549

This shows an increase of upwards of 7·41 per cent. on the present number during the last twelve months—a rate of increase which was only exceeded in the years 1865 and 1866, and which has not been nearly equalled in any other year except 1867, when there was an increase of 7·02 per cent.

The Students are not included in the above enumeration, as they do not belong to the Corporation. Up to the 30th of November last, there had been 133 admissions to this class; so that if that number be added to the gross total previously given, it will be found that the Students form at present between one-twelfth and one-thirteenth of the different classes of the Institution. The maximum reached by the old class of Graduates, created on the 26th of December, 1837, was one-eighth, after being nearly five years in operation, at which time the elections into that class ceased. It will be remembered that the class of Students was created in 1867, so that it has only been in existence one session.

The following Member and Associates, having tendered their resignations in writing, have been permitted to retire from the Institution:—Albert Robinson, Member; James Andrew Agnew, John Joseph Bagnell, Capt. George Henry Basevi, Arthur Collinge, Henry William Harman, John Morgan, William Wilson Poingdestre, George Pownall, Fraser Selby, and Bergerius Sörenson.

The deceases announced during the year have been:—Sir David Brewster and Lord Brougham, Honorary Members; George Row-

don Burnell, Alexander Gordon, Daniel Gallagher Grose, George Alfred Jermyn, Michael Lane, George Holsworthy Palmer, Thomas Rhodes, and William Swinburne, Members; Henry Goulburn Anderson, Thomas Long Colley, Isaac Curran, Andrew Henderson, Peter Hogg, Frederic Cornell Reynolds, Robert Sharpe, Francis Adolphus Smart, Thomas Hitchin Smith, William Strode, William Swann, and John Vaughan, Associates.

Biographical notices of some of those whose loss the Institution has thus to deplore will be given in an Appendix to this volume.

The deaths recorded during the last twelve months have averaged a fraction over 14 in the thousand on the present number of members. Two distinguished Honorary Members have been thus removed from the list. One, Sir David Brewster, was the oldest Honorary Member on the register, having been borne on the books of the Institution since the year 1820. The other, Lord Brougham, was elected in 1842. Among the Members two joined the Institution in the year 1827, one in 1832, another in 1833, a fifth in 1838, while the others were elected so recently as 1861, 1866, and 1867. Of the Associates one had belonged to the Institution for the long period of twenty eight years, another for twenty seven years, four for nineteen, eighteen, sixteen, and twelve respectively, while the remaining six had been elected since the year 1860.

The following summary of the Statement of Receipts and Expenditure, as signed by the Auditors, will serve to show briefly, the sources of income, and the manner in which that income has been disbursed.

The ordinary Receipts have comprised :—

	1867.						1868.					
	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.
From subscriptions, fees, &c., exclusive of Building Fund	4,657	10	0				5,358	0	10			
„ dividends on investments not in trust	484	5	8				480	18	0			
				5,141	15	8				5,838	18	10
„ Building Fund fees, on election . .	715	1	0				798	0	0			
„ dividends on investments on this account . . .	129	0	7				134	10	1			
				844	1	7				932	10	1
„ dividends on Trust Funds . . .	. .			371	15	5	. .			401	19	6
Total . .				£6,357	12	8				£7,173	8	5

The Expenditure during the same period (exclusive of the new building) has been :—

	£. s. d.	£. s. d.	£. s. d.
To disbursements, including Minutes of Proceedings (less received on that account) .	. .	4,446 4 10	. . 3,461 5 4
„ Premiums under Trusts . . .	. .	163 10 3	. . 161 7 5
„ Investments :—			
Telford Fund (unexpended dividends) . .	185 10 7		
Miller Fund, ditto	230 6 2		
General account .	. .		. . 1,250 0 0
Building Fund .	1,222 4 6		
		1,638 1 3	
		£6,247 16 4	£4,872 12 9

It was stated in a Report of the Finance Committee of the Council, dated February 20, 1868, prepared at the request of the President, that—

The annual income, exclusive of all receipts of life compositions, building fund fees, and dividends of every kind, might be safely estimated at	£4,925
While the annual expenditure would not exceed	4,321
Showing a surplus of	£604
During the past year the income from the sources above indicated has been . .	£5,406 10 1
And the disbursements	3,667 4 8
Leaving a surplus of	£1,739 5 5

But when to this sum is added the above excluded items, still disregarding all trust moneys, the surplus is £3,310. 8*s.* 6*d.*

Finding, in the early part of the session, that the balance at the bankers was more than was likely to be immediately required, a sum of £1,250 was invested in the purchase of £1,344. 1*s.* 8*d.* New Three per Cents. This still remains in possession of the Institution.

After it was decided to proceed with the new building, Mrs. Locke's special donation of £200, together with the accumulated interest, was withdrawn from deposit at the Union Bank, and was paid into the credit of the general account, at Messrs. Coutts' and Co.; and the Treasurer also received from the Court of Chancery

the Locke Bequest of £2,000. Subsequently, as the works of the new building progressed, it became necessary to dispose of stock to meet the Architect's certificates. In this way the whole of the Building Fund was first absorbed. The stocks to the credit of this fund, as stated in the last Annual Report, were of the nominal value of £4,287. 14*s.* 7*d.* They had been purchased at a cost of £4,032. 14*s.* 6*d.*, and have realized £3,983. 0*s.* 7*d.*, so that there has been a loss of capital by their sale to the extent of £49. 13*s.* 11*d.* The Miller Bequest of £2,000 was invested by the executors in £2,133. 6*s.* 8*d.* Consols. This has realized £1,977. 11*s.* 10*d.*, resulting in a loss of capital of £22. 8*s.* 2*d.* These were all the securities that had been sold at the close of the financial year of the Institution on the 30th of November last, to which date the accounts are made up and audited. Since then the Stephenson Bequest of £2,000 and the Errington Bequest of £1,000, which had been invested at par in Four per Cent. Debenture Stocks of the North Eastern and the Great Northern Railway Companies respectively, have been disposed of for £1,915.7*s.* 6*d.* and £987.10*s.* 9*d.*, involving a loss of capital (including brokerage) of £84. 12*s.* 6*d.* in one case, and of £12. 9*s.* 3*d.* in the other. Of the Institution investments, £1,400 Great Northern Railway Four per Cent. Debenture Stock, which was purchased for £1,374. 4*s.*, has been sold for £1,382. 11*s.*, thus showing a gain of £8. 7*s.* The total difference between the purchase money and the sale price of the several stocks already disposed of, or the actual loss of capital by their sale, has been £168. 6*s.* 10*d.* It should however be stated that, in the Report from the Council upon the Building Question, presented at the Special General Meeting of Members and Associates on the 7th day of April, 1868, these stocks were only estimated to realize £9,818, whereas they have actually produced £10,246. 1*s.* 8*d.*

The Funds of the Institution consisted on the 30th of November last—but some of these stocks have since been sold, as before stated—of

I. General Funds.

		Nominal Value. £.	*s.*	*d.*	
1. Stephenson Bequest, North Eastern Railway Four per Cent. Debenture Stock . .		2,000	0	0	
2. Errington Bequest, Great Northern Railway Four per Cent. Debenture Stock . .		1,000	0	0	
3. Institution Investments:—					
Great Eastern Railway Four per Cent. Debenture Stock .	£3,650 0 0				
Great Northern ditto . .	1,400 0 0				
London and North Western ditto	1,162 0 0				
London, Brighton, and South Coast Company ditto . .	1,000 0 0				
North Eastern ditto . .	500 0 0				
New Three per Cents. . .	1,344 1 8				
		9,056	1	8	
					12,056 1 8

	£.	s.	d.
Brought forward . . .	12,056	1	8

II. TRUST FUNDS.

1. Telford Fund:—						
Three per Cent. Consols . .	£2,551	15	10			
Ditto . .	287	15	0			
Three per Cent. Annuities .	2,342	17	1			
Ditto . .	227	8	0			
				5,409	15	11
Ditto Unexpended Dividends, Three per Cent. Consols . .	1,775	19	8			
Ditto, Annuities .	601	10	9			
Ditto do. .	200	11	5			
				2,578	1	10
						7,987 17 9
2. Manby Premium :—						
Great Eastern Railway, Norfolk Five per Cent. Preference Stock						200 0 0
3. Miller Fund :—						
Lancashire and Yorkshire Railway Four per Cent. Debenture Stock .	£2,000	0	0			
Great Eastern ditto . .	1,100	0	0			
				3,100	0	0
Unexpended Dividends, Three per Cent. Consols	582	18	6			
Ditto, Annuities	248	19	8			
				831	18	2
						3,931 18 2
						12,119 15 11
Total Nominal Value of different Securities . . .						24,175 17 7
Cash in the hands of the Treasurer, Dec. 1, 1868						1,262 8 8
Less Balance of Petty Cash due to the Secretary						29 13 10
						1,232 14 10
Together amounting to						£25,408 12 5

as against £29,835. 18*s.* at the date of the last Report.

There has been a decrease within the financial year of £4,427. 5*s.* 7*d.*; but it is to be remarked, that a sum of £9,711. 16*s.* 10*d.* was paid in that period on account of the new building and its accessories, towards which the only special receipts contributed during the year were the Locke Donation and Bequest, together amounting, with interest, to £2,262. 1*s.* 1*d.*, showing that the balance £3,022. 10*s.* 2*d.* has been derived from the excess of gross income over ordinary expenditure.

The following is a Summary of the different Securities in which the above Funds are placed :—

	£.	s.	d.	£.	s.	d.
Government Stocks :—						
Three per Cent. Consols	5,198	9	0			
Three per Cent. Annuities	3,621	6	11			
New Three per Cents.	1,344	1	8			
				10,163	17	7
Great Eastern Railway :—						
Five per Cent. Preference Stock . . .	200	0	0			
Four per Cent. Debenture Stock . . .	4,750	0	0			
				4,950	0	0
Great Northern Railway :—						
Four per Cent. Debenture Stock . . .				2,400	0	0
Lancashire and Yorkshire Railway :—						
Four per Cent. Debenture Stock . . .				2,000	0	0
London and North Western Railway :—						
Four per Cent. Debenture Stock . . .				1,162	0	0
London, Brighton, and South Coast Railway :—						
Four per Cent. Debenture Stock . . .				1,000	0	0
North Eastern Railway :—						
Four per Cent. Debenture Stock . . .				2,500	0	0
Total Nominal Value . . .				£24,175	17	7

The amount of Subscriptions still remaining due on the 30th of November last, from members of all classes (exclusive of those who are more than three years in arrear, including the current year) is :—

		£.	s.	d.	£.	s.	d.
For 1868.	From members of all classes residing abroad	71	18	6			
	Ditto, in the United Kingdom . .	248	17	0			
					320	15	6
For 1867.	From members of all classes residing abroad	27	6	0			
	Ditto, in the United Kingdom . .	83	9	6			
					110	15	6
For 1866.	From members of all classes residing abroad	6	6	0			
	Ditto, in the United Kingdom . .	45	13	6			
					51	19	6
	Total . . .				£483	10	6

Several applications have been made to the Council for the temporary use of the theatre of the Institution for the meetings of other Societies. The Bye-laws do not appear to give the Council the power to make such a grant, except in the case of "persons who may be desirous of having Lectures delivered on subjects connected with the objects of the Institution." The Council believe that in some cases such a grant might be made without impropriety or inconvenience to the members of the Institution; but it has been deemed advisable to bring the subject under the consideration of the General Meeting, in order that, if thought expedient, the necessary authority may be obtained.

In the preparation of the Balloting List for Council, the Rules and Regulations have been strictly adhered to; and it only remains

to be added that, in consenting to allow their names to appear on the list, Messrs. Samuda and Woods, Members; and Sir Wm. Denison, Sir R. A. Glass, and Messrs. Ransome and De Bergue, Associates, have one and all promised, if elected, to do their utmost to further the best interests of the Institution.

The Council have much pleasure in submitting this narrative of heir administration, during a season of unusual responsibility, and they hope their labours have been attended with advantage to the Institution.

[ABSTRACT

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	s.	d.	£.	s.	d.
To Balance of Petty Cash, December 1, 1867, in the hands of the Secretary				13	5	8
— Balance in the hands of the Treasurer				367	13	4
— Subscriptions and Fees:—						
Arrears	221	0	6			
Current	4,268	5	0			
Subscriptions for 1869 (in advance)	25	14	6			
Fees	466	4	0			
Life Compositions	157	10	0			
				5,138	14	0
— Building Fund				798	0	0
— Publication Fund				126	0	0
— Council Fund				50	0	0
— Publications:—Sale of Transactions				205	19	3
— Telford Premiums:—						
Repayment of Cost of Building, &c.				33	14	6
— Telford Fund:—						
Dividends—1 Year, on £2,839. 10*s.* 10*d.*, Three per Cent. Consols	83	2	10			
Ditto, 1 Year, on £2,570. 5*s.* 1*d.*, Three per Cent. Annuities	75	3	5			
Ditto, 1 Year, on £2,377. 10*s.* 5*d.*, Three per Cent. Consols (Unexpended Dividends)	69	12	2			
Ditto, 1 Year, on £200. 11*s.* 5*d.*, Three per Cent. Annuities (Unexpended Dividends)	5	16	8			
				233	15	1
— Manby Premium:—						
Dividends, 2 Years, on £200, Great Eastern Railway Company, Five per Cent. Preference Stock				22	17	10
— Stephenson Bequest:—						
Dividends, 1 Year, on £2,000, North Eastern Railway Company, Four per Cent. Debenture Stock				78	3	4
— Miller Fund:—						
Dividends, 1 Year, on £2,000, Lancashire and Yorkshire Railway Company, Four per Cent. Debenture Stock	78	3	4			
Ditto, 1 Year, on £1,100, Great Eastern Railway Company, Four per Cent. Debenture Stock	42	18	10			
Ditto, 1 Year, on £582. 18*s.* 6*d.*, Three per Cent. Consols (Unexpended Dividends)	16	18	0			
Ditto, 1 Year, on £248. 19*s.* 8*d.*, Three per Cent. Annuities (Unexpended Dividends)	7	6	5			
				145	6	7
— Miller Bequest:—						
Dividends, 1 Year, on £2,133. 6*s.* 8*d.*, Three per Cent. Annuities				62	8	0
— Errington Bequest:—						
Dividends, 1 Year, on £1,000, Great Northern Railway Company, Four per Cent. Debenture Stock				39	1	10
— Institution Investments:—						
Dividends, 1 Year, on £3,650, Great Eastern Railway Company, Four per Cent. Debenture Stock	142	9	6			
Carried forward	142	9	6	7,314	19	5

from the 1ST DEC., 1867, *to the* 30TH NOV., 1868.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George Street, for Rent, &c.:—						
Repairs	22	19	7			
Furniture	9	7	11			
Rent	387	10	0			
Rates and Taxes	31	0	3			
Insurance	19	10	0			
				470	7	9
— Salaries				825	0	0
— Clerks, Messengers, and Housekeeper				328	2	0
— Postage and Parcels:—						
Postage	48	3	5			
Parcels	0	14	11			
				48	18	4
— Stationery, Engraving, Printing Cards, Circulars, &c.				109	5	9
— Coals, Candles, Oil, and Gas:—						
Coals	25	19	6			
Candles	0	3	0			
Oil	1	6	0			
Gas	30	16	7			
				58	5	1
— Tea and Coffee				49	16	9
— Library:—						
Books	88	15	7			
Periodicals	19	13	10			
Binding Books	162	8	10			
Evening Attendance	65	0	0			
Catalogue	2	13	7			
				338	11	10
— Publication, Minutes of Proceedings				1,155	5	5
— Telford Premiums				135	5	5½
— Watt Medal				3	17	0
— Miller Premium				0	7	2
— Manby Premium				10	19	9
— Manby Premium:—						
Return of Advance made by Donor, as per last Statement				14	15	0
— Diplomas				16	1	1
— Manuscripts, Original Papers, and Drawings				56	6	7
— Annual Dinner				95	15	0
— Incidental Expenses:—						
Christmas Gifts	2	0	6			
Assistance at Meetings	11	6	0			
Beating Carpets and Sweeping Chimneys	0	11	0			
Household Utensils, Repairs, and Expenses	39	15	2½			
				53	12	8½
Carried forward				3,770	12	8

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
Brought forward . .	142	9	6	7,314	19	5
Dividends, 1 Year, on £1,400, Great Northern Ditto	54	14	5			
Ditto, 1 Year, on £1,162, London and North Western Ditto	46	8	5			
Ditto, 1 Year, on £1,000, London and Brighton Ditto	39	1	8			
Ditto, 1 Year, on £500, North Eastern Ditto. .	18	10	10			
				301	4	10
To Building Fund Investments:—						
Dividends, 1 Year, on £500, Great Northern Railway Company, Four per Cent. Debenture Stock	19	10	7			
Ditto, 1 Year, on £1,338, London and North Western Ditto	52	5	9			
Ditto, 1 Year, on £1,100, Great Eastern Ditto .	42	18	10			
Ditto, ½ Year, on £913, Three per Cent. Consols	13	7	3			
Ditto ½ Year, on £435. 18s. 5*d.*, Three per Cent. Annuities	6	7	8			
				134	10	1
— Donations to Library				31	18	6
— Library				0	1	10
— Benevolent Fund.				39	1	3
— Benevolent Fund. Subscription paid to wrong account in error .				1	1	0
— Globe Insurance Company. Return of excess of cheque drawn in error				0	5	0
— Sale of old materials				11	6	6
				£7,834	8	5
— Locke Donation to New Building Fund	200	0	0			
Bank Interest	9	16	2			
				209	16	2
— Locke Bequest	2,000	0	0			
Interest	52	4	11			
				2,052	4	11
— Proceeds of Sale of Stocks :—						
£1,349. 14s. 7*d.*, Three per Cent. Consols .	1,271	0	11			
£1,338, London and North Western Railway, Four per Cent. Debenture Stock . .	1,291	7	5			
£1,100, Great Eastern Ditto	933	1	3			
£500, Great Northern Ditto	487	11	0			
£2,133. 6s. 8*d.*, Three per Cent. Reduced Consols	1,977	11	10			
				5,960	12	5
— Balance due to the Secretary				29	13	10
				£16,086	15	9

from the 1ST DEC., 1867, *to the* 30TH NOV., 1868.

PAYMENTS.

Cr.	£.	*s.*	*d.*	£	*s.*	*d.*
Brought forward . .				3,770	12	8
To Legal Expenses				52	10	0
— Engineering Education				5	9	4
— Benevolent Fund				33	18	3
				3,862	10	3
— New Building :—						
Contract	9,000	0	0			
Warming and Ventilating . . .	250	0	0			
Expenses Removing	76	0	1			
Rent of Temporary Offices . .	300	0	0			
Incidental Expenses	85	16	9			
				9,711	16	10
				13,574	7	1
— Finance Committee for purchase of £1,344. 1*s.* 8*d.*, New Three per Cents.				1,250	0	0
— Balance in the hands of the Treasurer				1,262	8	8
				£16,086	15	9

Examined and compared the above Account with the Vouchers and the Cash Book, and find this account to be correct, leaving a Balance in the hands of the Treasurer of Twelve Hundred and Sixty-two Pounds, Eight Shillings, and Eightpence.—Nov. 30th, 1868.

(Signed) JAMES D. BALDRY, CHARLES E. HOLLINGSWORTH. } *Auditors.*
JAMES FORREST . . . . . *Secretary.*

December 19th, 1868.

PREMIUMS AWARDED.

Session, 1867-68.

The Council of The Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, and a Telford Premium, in Books, to George Higgin, M. Inst. C.E., for his Paper "Irrigation in Spain, chiefly in reference to the Construction of the Henares and the Esla Canals in that country."
2. A Telford Medal, and a Telford Premium, in Books, to Christer Peter Sandberg, Assoc. Inst. C.E., for his Paper "On the Manufacture and Wear of Rails."
3. A Telford Medal, and a Telford Premium, in Books, to Lieut.-Colonel Peter Pierce Lyons O'Connell, R.E., Assoc. Inst. C.E., for his Paper "On the Relation of the Fresh-Water Floods of Rivers to the Areas and Physical Features of their Basins."
4. A Telford Medal, and a Telford Premium, in Books, to William Wilson, M. Inst. C.E., for his "Description of the Victoria Bridge, on the line of the Victoria Station and Pimlico Railway."
5. A Telford Medal, and a Telford Premium, in Books, to Charles Douglas Fox, M. Inst. C.E., for his Paper "On New Railways at Battersea; with the Widening of the Victoria Bridge and Approaches to the Victoria Station."
6. A Telford Medal, and a Telford Premium, in Books, to John Wolfe Barry, M. Inst. C.E., for his Paper "On the City Terminus Extension of the Charing Cross Railway."

*7. A Watt Medal to Edwin Clark, M. Inst. C.E., for his Paper "On Engineering Philosophy: the Durability of Materials."

8. A Telford Medal to William Jarvis McAlpine, M. Inst. C.E., for his Paper "On the Supporting Power of Piles; and on the Pneumatic Process for sinking Iron Columns, as practised in America."
9. A Telford Premium, in Books, to Thomas Login, M. Inst. C.E., for his Paper "On the Benefits of Irrigation in India; and on the Proper Construction of Irrigating Canals."

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* Has previously received a Telford Medal.

10. A Telford Premium, in Books, to Allan Wilson, M. Inst. C.E., for his Paper "On Irrigation in India."
11. A Telford Premium, in Books, to Wilfrid Airy, Assoc. Inst. C.E., for his Paper "On the Experimental Determination of the Strains on the Suspension Ties of a Bowstring Girder."
12. The Manby Premium, in Books, to Andrew Cassels Howden, Assoc. Inst. C.E., for his Paper "On Floods in the Nerbudda Valley; with Remarks on Monsoon Floods in India generally."

SUBJECTS FOR PREMIUMS.

Session, 1868-69.

The Council of The Institution of Civil Engineers invite communications on the Subjects comprised in the following list, as well as upon others; such as—1. Authentic Details of the Progress of any Work in Civil Engineering, as far as absolutely executed (Smeaton's Account of the Edystone Lighthouse may be taken as an example); 2. Descriptions of Engines and Machines of various kinds; or, 3. Practical Essays on Subjects connected with Engineering, as, for instance, Metallurgy. For approved Original Communications, the Council will be prepared to award the Premiums arising out of special Funds devoted for the purpose.

1. On the present State of Knowledge as to the Strength of Materials.
2. On Steam Cranes, and on the Application of Steam Power in the execution of Public Works.
3. On the Theory and Details of Construction of Metal and Timber Arches.
4. On Land-slips, with the best means of preventing, or arresting them, with examples.
5. On the Principles to be observed in Laying-out lines of Railway through mountainous countries, with examples of their application in the Alps, the Pyrenees, the Indian Ghâts, the Rocky Mountains of America, and similar cases.
6. On Railway Ferries, or the Transmission of Railway Trains entire across Rivers, Estuaries, &c.
7. On the Systems of Fixed Signals at present in use on Railways.
8. Description of a Modern English Locomotive Engine, designed with a view to cheapness of construction, durability, and facility of repair.
9. On the leading points of difference between the Engines and Carriages in use on Railways in the United States and in Great Britain, and the reasons for any peculiarities in the American practice, with details of the cost of maintenance.

10. On the most suitable Materials for, and the best mode of formation of, the Surfaces of the Streets of large Towns.
11. On the Construction of Catch-water Reservoirs in Mountain Districts, for the Supply of Towns, for Irrigation, or for Manufacturing Purposes.
12. Accounts of existing Waterworks; including the source of supply, a description of the different modes of collecting and filtering, the distribution throughout the streets of Towns, and the general practical results.
13. On Pumping Machinery for raising water, both for high and low lifts.
14. On the Drainage of Towns, and the ultimate disposal of town refuse.
15. On the Employment of Steam Power in Agriculture.
16. On the Ventilation and Warming of Public Buildings.
17. On the Design and Construction of Gas Works, with a view to the Manufacture of Gas of high illuminating power; and on the most economical system of distribution of Gas, and the best modes of Illumination in Streets and Buildings.
18. Critical Observations on Estuary Tides.
19. On the Construction of Tidal, or other Dams, in a constant, or variable depth of water; and on the use of Wrought Iron in their construction.
20. On the Arrangement and Construction of Floating Landing-Stages, for passenger and other traffic, with existing examples.
21. On the different systems of Swing, Lifting, and other opening Bridges, with existing examples.
22. On the Measure of Resistance to Bodies passing through Water at high Velocities.
23. On the results of the best modern practice in Ocean Steam Navigation, having regard particularly to economy of working expenses, by super-heating, surface condensing, great expansion, high pressure, &c.; and on the "life" and cost of maintenance of Merchant Steam Ships.
24. On Ships of War, with regard to their Armour, Ordnance, mode of Propulsion, and Machinery.
25. On the measures to be adopted for protecting Iron Ships from Corrosion.
26. On Coal Mining in Deep Workings, including machinery for dispensing with gunpowder in "getting" Coal.
27. On the present Systems of Smelting Iron Ores; of the conversion of Cast-iron into the malleable state, and of the manufacture of Iron generally, comprising the distribution and arrangement of Iron Works.

28. On Machinery for Rolling Heavy Rails, Shafts, and Bars of large sectional area, and for Forging heavy masses of Metal.
29. On Steel, and its present position as regards production and application.
30. On the safe working strength of Iron and Steel, including the results of experiments on the Elastic Limit of long Bars of Iron, and on the rate of decay by rusting, &c., and under prolonged strains.
31. On Machinery for Washing Lead Ores.
32. On the present state of Submarine Telegraphy, and on the Transmission of Electrical Signals through Submarine Cables.

The Council will be glad to receive, for the purpose of forming an "Appendix" to the Minutes of Proceedings, the details and results of any Experiments, or Observations, on Subjects connected with Engineering Science, or Practice.

The Council will not consider themselves bound to award any Premium, should the Communication not be of adequate merit, but they will award more than one Premium, should there be several communications on the same subject deserving this mark of distinction. It is to be understood that, in awarding the Premiums, no distinction will be made, whether the Communication has been received from a Member, or an Associate of the Institution, or from any other person, whether a Native, or a Foreigner.

The Communications must be forwarded, on or before the 1st of February, 1869, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where copies of this Paper, and any further information, may be obtained.

CHARLES MANBY, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

25, *Great George Street, Westminster, S.W.,*
October, 1868.

NOTICE.

It has frequently occurred that, in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a

body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

Extracts from the Minutes of Council, Feb. 23rd, 1835.

The principal Subjects for which Premiums will be given are:—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed, and which shall contain authentic details of the progress of the work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

"2ndly. Models or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering or Surveying."

Excerpt Bye-Laws, Section XV., Clause 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same, in any way and at any time they may think proper; but should the Council refuse, or delay the publication of such Paper, beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish

it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

Instructions for preparing Communications.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and a half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, should be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN DECEMBER 1st, 1867, AND NOVEMBER 30th, 1868.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Airy, W. No. 1207.—On the Archimedean Screw for Lifting Water.

Barry, J. W. No. 1198.—The City Terminus Extension of the Charing Cross Railway.

Bidder, S. P., Jun. No. 1211.—On Machines employed in Working and Breaking down Coal, so as to Avoid the use of Gunpowder.

Burt, J. M. No. 1197.—On the most suitable Materials for, and the best Foundations of, the Surfaces of Streets in large Towns.

Christy, F. C. No. 1205.—On the Working of the Victorian Government Railways.

Green, W. No. 1208.—On a means of Removing the Snow from the Streets, and of disposing of it rapidly.

Green, W. No. 1206.—On Shortened Muzzle Loading as a means of enabling the Turrets or Towers of Fighting Ships to be Reduced in Size.

Henderson, D. M. No. 1203.—On Lighthouse Apparatus and Lanterns.

Higgin, G. No. 1204.—Irrigation in Spain; chiefly in reference to the construction of the Henares and the Esla Canals in that Country.

Langley, A. A. No. 1192.—Power-Storing Breaks for Railways.

Login, T. No. 1200.—On the Benefits of Irrigation in India; and on the Proper Construction of Irrigating Canals.

Mallet, R. T. No. 1199.—Telemeters; or, Instruments for the Indirect Measurement of Distances.

Mosse, J. R. No. 1202.—The Mauritius Railways: Midland Line.

Sandberg, C. P. No. 1196.—On the Manufacture and Wear of Rails.

AUTHORS.

Sparkes, Lieut. J. B. No. 1210.—An Account of the Construction of a Masonry Dam across the Morar River, in the Cantonment of Morar Gwalior.

Stewart, J. No. 1190.—On the Steam Navigation of Shallow Rivers, as experienced in New Zealand.

——— No. 1191.—Report on the Proposed Railway Extension to Waikato.

Wheeler, W. H. No. 1209.—The History, Management, Construction, Repair, and Cost of the Roads of England and Wales.

White, C. F. No. 1195.—Description of the Line and Works of the South Eastern Railway of Portugal.

Wilson, A. No. 1193.—On Irrigation in India.

CATALOGUE OF PRESENTS.

BOOKS.

DONORS. TITLE OF WORK.

Académie Royale de Belgique. Annuaire, 1868. 12mo. Portrait. Bruxelles, 1868.

———— Bulletins. Tome XXIV. 8vo. Bruxelles, 1867.

———— Mémoires Couronnés et autres Mémoires. Tomes XIX., XX. 2 vols. 8vo. Plates. Bruxelles, 1867-68.

———— Mémoires Couronnés et Mémoires des Savants Étrangers. Tome XXXIII. 1865-67. 4to. Plates. Bruxelles, 1867.

Adams, W. B. Railway Practice and Railway Possibilities. By W. Bridges Adams. Tract. 8vo. Plates. London, 1868.

Admiralty, through the Astronomer Royal. Astronomical and Magnetical and Meteorological Observations made at the Royal Observatory, Greenwich, during the year 1866, under the direction of George Biddell Airy, Astronomer Royal. 4to. London, 1868.

———— Rates of Chronometers on trial for purchase by the Board of Admiralty at the Royal Observatory, Greenwich, 1868. Tract. 4to. No place, 1868.

———— Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, Greenwich, Read at the Annual Visitation of the Royal Observatory, 1868, —June 6. 4to. No place, 1868.

American Academy of Arts and Sciences. Memoirs. Old Series. Vols. I.—IV. 4 vols. 4to. Cambridge, 1785-1821.

———— Do. Do. New Series. Vols. I.—IX., Part I. 9 vols. 4to. Plates. Cambridge and Boston, 1833-67.

———— Proceedings. Selected from the Records. Vols. I. to VII., p. 344. 7 vols. 8vo. Plates. Cambridge and Boston, 1848-67.

Anonymous. Langlois Moveable Tubes. Patented in France and abroad for Marine, Stationary, Locomotive, and Portable Steam Boilers. Tract. 4to. Plate. Cherbourg, 1867.

———— Notes on Submarine Mines, commonly called Torpedoes. By Captain Harding Steward, R.E. Tract. 8vo. Woolwich, 1866.

Architecten und Ingenieur Vereins zu Hannover. Zeitschrift. Band XIII. Hefte II. III. and IV. Folio. Plates and Cuts. Hannover, 1867-68.

DONORS. TITLE OF WORK.

Art Union of London. Report of the Council of the Art Union of London for the year 1867. Tract. 8vo. 1867. Thirty-first Annual Report of the Art Union of London, with Lists of Members. 8vo. London, 1867.

Association for the Prevention of Steam Boiler Explosions, Manchester. Chief Engineers' Monthly Reports to Executive Committee. Nos. LXXI.—LXXXII. December, 1867, to November, 1868. 8vo. Cuts. Manchester, 1867-68.

———— Report of Messrs. Nicoll and Lynn, to the Admiralty, of the trials at Wigan of the Steam Coals of South Lancashire and Cheshire. P.P., 16th August, 1867.

———— Report of the Committee of Management, to be presented to the Subscribers at the Annual Meeting, to be held at the Town Hall, Manchester, on Tuesday, March 10, 1868. Tract. 8vo. Manchester, 1868.

Athenæum Club. Catalogue of the Library of the Athenæum Club. Vol. I. 1845-51—Vol. II. 1851-66. 2 vols. 8vo. London. Various dates.

Babut de Marés, M. Avant Projet d'un Tunnel réliant les Chemins de Fer de la France et de l'Angleterre. 4to. Plates. Mons, 1867.

Baird, Mrs. Memoir of the late Charles Baird, Esq., of St. Petersburgh, and of his Son, the late Francis Baird, Esq. By T. Tower. 8vo. Plates. London, 1867.

Balfour, J. M. New Zealand Exhibition, 1865. Reports and Awards of the Jurors. Appendix. 8vo. Dunedin, 1866.

Balfour, Major-General, through A. Wilson. Public Works in India; their importance. With suggestions for their Extension and Improvement. By Lieut.-Col. A. Cotton. Revised Indian edition of March, 1854. 8vo. Calcutta, 1854.

Barnum, Hon. W. W., through W. W. Evans. Reports of Experiments on the Properties of Metals for Cannons, and the Qualities of Cannon Powder; with an account of the fabrication and trial of a 15-inch Gun. By Captain T. J. Rodman. 4to. Plates and Cuts. Boston, 1861.

———— Reports of Experiments on the Strength and other properties of Metal for Cannon, with a Description of the Machines for Testing Metals, and of the Classification of Cannon in Service. By Officers of the Ordnance Department, U. S. Army. 4to. Plates and cuts. Philadelphia, 1856.

Barroso, Z. Pharoes. Estudias sobre a Illuminação da Costa do

DONORS. TITLE OF WORK.

Brazil. Pelo Engenheiro Zosimo Barroso. 8vo. Londres, 1868.

Barry, E. M. The Architect of the New Palace of Westminster. A Reply to the Statements of Mr. E. W. Pugin. By Rev. Alfred Barry, D.D. 8vo. Photograph, 1868.

Barry, J. D. Ministerio de Fomento. Ley de Aguas. 8vo. Madrid, 1866.

Barry, Lady. The Life and Works of Sir Charles Barry, R.A., F.R.S. By Rev. Alfred Barry, D.D. 8vo. Portrait. Plates and cuts. London, 1867.

Bateman, J. F. Belfast Water Works. Report on the Supply of Water to the Town of Belfast. By J. F. Bateman, together with a report on the Improvement of the Old Works by Charles Lanyon, and Analysis of Water by Professor Thos. Andrews. Tract. 8vo. Map. Manchester, 1856.

——— Description of the Manchester Water Works. By J. F. Bateman. Tract. 8vo. Plates. Birmingham, 1867.

[Excerpt "Proc. Inst. M. E.," 1866.]

——— Glasgow Water Works. Supply of Water from Loch Katrine. Summary of Description given to Section G of the British Association at the Meeting at Aberdeen, 1859. Tract. 8vo. No place or date.

——— On a Constant Supply of Water to London. By J. F. Bateman. Tract. 8vo. London, 1867.

[Read before the National Association for the Promotion of Social Science, 1867.]

——— Report on the quantity of Rain falling on the lines of the Rochdale, Ashton-under-Lyne and Peak Forest Canals. By Peter Clare and J. F. Bateman; with Observations on the Returns, and other particulars by J. F. Bateman. Tract. 8vo. Manchester, 1854.

[Read before the Literary and Philosophical Society of Manchester, 1848.]

Bazalgette, J. W. Minutes of the Joint Committee of the Magistrates and Council, the Clyde Trustees, and the Board of Police, on the subject of the Sewage of Glasgow, and the Purification of the River Clyde; with Report of Messrs. Bateman and Bazalgette in pursuance of the instructions by the Joint Committee. Folio. Plates. Glasgow, 1868.

Beazeley, M. An Attempt to Determinate the Styles of Architecture in England, from the Conquest to the Reformation; with a sketch of the Grecian and Roman Orders. By Thomas Rickman. Sixth edition, with considerable

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additions, chiefly historical, by John Henry Parker. 8vo. Plates and cuts. Oxford, 1862.

Bell and Daldy, Messrs. A short answer to Mr. Freeman's Strictures in the "Fortnightly Review" on the "History of England during the early and middle ages." By Charles H. Pearson. Tract. 8vo. London, 1868.

Benton, Col., through W. W. Evans. A course of Instruction in Ordnance and Gunnery; prepared for the use of the Cadets in the United States Military Academy. By Brevet-Col. J. G. Benton. Third edition, revised and enlarged. 8vo. Cuts. New York, 1868.

Beresford-Hope, A. J. B. Metric Weights and Measures. Speech of Mr. Beresford-Hope, M.P., in moving the rejection of the Metric Weights and Measures Bill, Wednesday, May 13, 1868. Tract. 8vo. London, 1868.

Bidder, G. P. Address to the Mechanical Science Section of the British Association, Norwich, August 20, 1868. By George Parker Bidder, C.E., President. Tract. 8vo. No place, 1868.

Bignami, E. I Canali nella Citta di Milano. Considerazione e Proposti di Emilio Bignami. 8vo. Plate. Milano, 1868.

Bingham, H. C. The Terra Cotta Architecture of North Italy (XIV. to XV. centuries). Portrayed, as examples for imitation in other countries, from careful Drawings and Restorations, by Frederigo Lose. Edited by Lewis Gruner. Folio. Plates. London, 1867.

Blashfield, J. M. Terra Cotta Chimney Shafts, Chimney Ornaments, &c., manufactured by John Marriott Blashfield, Stamford. Folio. Plates. Stamford and London, 1866-67.

Board of Trustees of the Public Schools of the City of Washington. Twenty-second Annual Report. 8vo. Plate. Washington, 1867.

Bodleian Library. Donations to the Bodleian Library during the year ending November 8, 1867. Tract. 8vo. Oxford. No date.

Bright, H. The Tramway Question, as applied to London and its Suburbs. By Herbert Bright. Tract. 8vo. Plates. London, 1868.

British Association of Gas Managers. Report of Proceedings of the Fifth Annual Meetings, held at the Rooms of the Society of Arts, London, June, 1868. 8vo. Plates. London, 1868.

———— Rules and Regulations and List of Members, 1868. Tract. 8vo. London, 1868.

DONORS. TITLE OF WORK.

British Association for the Advancement of Science. Report of the Thirty-seventh Meeting, held at Dundee in September, 1867. Plates and cuts. London, 1867.

Buquet, A. De la Traction à Vapeur sur les Rivières et les Canaux. Notes et Documents par M. A. Buquet. Tract. 8vo. Plates. Liège, 1868.

Carruthers, J. Comptes-Rendus Hebdomadaires des Séances de l'Académie des Sciences. Vols. LIV.—LXIII. 1862-66. 10 vols. 4to. Plates. Paris, 1862-66.

Caruthers, J. Report of the Board of Directors of the Lehigh Valley Railroad Company to the Stockholders at the Annual Meetings, January 8, 1866, January 14, 1867, January 13, 1868. Three Tracts. 8vo. Philadelphia, 1866-68.

——— Nineteenth, Twentieth, and Twenty-first Annual Reports of the Board of Directors of the Pennsylvania Railroad Company to the Stockholders. Three Tracts. 8vo. Philadelphia.

——— Reports of the President and Managers of the Philadelphia and Reading Railroad Company to the Stockholders, Jan. 10, 1866, Jan. 14, 1867, Jan. 13, 1868. Three Tracts. 8vo. Philadelphia, 1866-68.

Cambridge Philosophical Society. Transactions. Vol. X. Part 2. Vol. XI. Part 1. 4to. Plates and cuts. Cambridge, 1864-66.

Chemical Society. Journal, Dec., 1867; Nov., 1868. 8vo. Cuts. London, 1867-68.

Childs, G. W. The Public Ledger Building, Philadelphia; with an account of the Proceedings connected with its opening, June 20, 1867. 8vo. Portrait, plate, photograph, and cuts. Philadelphia, 1868.

Cialdi, A. Sul Portosaido. Censura dell' Illustre Professor Pietro Paleocapa contro la Lettura del Comm. Cialdi al Signor de Lesseps, e Risposta del Commendatore Alessandro Cialdi al Prof. Paleocapa. Tract. 8vo. Roma, 1868.

——— Port Saïd. A M. Ferdinand de Lesseps, President et Directeur de la Compagnie Universelle du Canal Maritime de Suez. Lettre du Comm. Alexandre Cialdi, Actionnaire de la même Compagnie. Avec un Post-Scriptum. Tract. 8vo. No place or date.

[Extrait du Giornale dell' Ingegnere, Architetto, ed Agronomo. XV^e an. Milan, 1867.]

Clark, D. K. Report of the Committee of Inquiry to the Shareholders of the Caledonian Railway Company, Jan. 3, 1868. Folio. London, 1868.

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Clark, L. On the Birmingham Wire Gauge. A Paper read to the British Association for the Advancement of Science, at Dundee, in September 1867. By Latimer Clark.

Clerk, Colonel H. Experiments on Friction. By Colonel H. Clerk. 8vo. Plates. Woolwich, 1868.

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January 12, 1869.

CHARLES HUTTON GREGORY, President,
the Chair.

The following Candidates were balloted for and duly elected:—
William Anderson and Frederick William Kitson, as Members: Christopher James Clarke, Edward Norton Clifton, Thomas Dyke, B.A., Richard Massey Greene, Thomas Hennell, Anthony Henry Kessner, Francis Langford O'Callaghan, Wilson Weatherly Phipson, Lewis William Pritchard, Warwick Stevens, William Henry Treverton, and Major Vidler, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—John Addy, John Baumann, John Brunlees, Alpin Grant Fowler, Oliver Claude Robson, Robert Sharland, George Stevens, and Joseph John Stiles.

The discussion upon the Papers, Nos. 1,211 and 1,217, "On Coal Breaking Machinery," occupied the whole evening, to the exclusion of any other subject.

January 19, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

The discussion upon the Papers, Nos. 1,211 and 1,217, "On Coal Breaking Machinery," occupied the whole evening, to the exclusion of any other subject.

January 26, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,181.—"Description of the New Ferry and the New Brighton Piers and Landing Stages on the River Mersey, near Liverpool." By Henry Hooper, Assoc. Inst. C.E.

In the session of 1860-61 the Author submitted a Paper, on the construction of a wrought and cast-iron pier at Southport, on the coast of Lancashire, from the designs of Mr. Brunlees, M. Inst. C.E.[1] The success of that work, in an engineering and commercial point of view, has led to the erection of many similar structures at various points on the coast of Great Britain; and believing that others will hereafter be formed on the same model, it is now proposed to describe two modifications of the principle, as carried out at the New Ferry Pier and Stage, and at the New Brighton Pier, both on the River Mersey, near Liverpool.

The ferry accommodation of the River Mersey comprises, on the west or Cheshire shore, commencing at the mouth of the estuary, first the New Brighton Pier and Landing Stage, forming a portion of the subject of this Paper. Proceeding up the stream, and still on the same shore, there are the Egremont and the Seacombe Landings, each consisting of an inclined way of stone, along which rails are laid, to allow of the passage up and down, according to the state of the tide, of a wrought-iron platform on wheels; the power for raising the platform being supplied by a stationary engine on the shore. These landings will probably soon be replaced by piers and floating stages. The New Brighton, the Egremont, and the Seacombe Landings are under the control of the Wallasey Local Board of Health. The next in position, provided by the Birkenhead Commissioners, is at Woodside. This consists of a wrought-iron floating stage, 800 feet in length, connected with the shore by wrought-iron bridges. Ascending the river, still in a southerly direction, this is succeeded by the inclined way, also of stone, which is used by the Chester and Birkenhead Railway Company as a landing-place for the passengers and luggage crossing by the railway boats from Liverpool. Following this is the inclined way of stone at Rock Ferry, the New Ferry Pier and floating stage, to

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 292 *et seq.*

be described in this Paper, and lastly, the wooden pier at Eastham, distant from New Brighton about 6 miles.

Crossing to the eastern or Lancashire shore, and descending the river towards the north, at a point nearly opposite Rock Ferry, is the South End floating stage, 120 feet long and 30 feet broad, with connecting bridge, all of wrought iron: and lastly, the well-known George's and Prince's stages, the former of which is 500 feet in length by 80 feet in breadth, carried on thirty-five pontoons, and connected with the shore by two bridges, each 150 feet in length; while the latter is 1,000 feet in length by 82 feet in breadth, and is connected with the shore by four bridges, each 113 feet in length.

It has been proposed to construct a pier and stage at Waterloo, at the mouth of the river, opposite to New Brighton. This is still a desideratum as regards the passenger traffic, and by indicating the channel, it would prove useful to vessels entering and leaving the port.

It having become evident that there was a want of communication by water, between the central and the southern portions of Liverpool, and New Ferry on the opposite shore, the Mersey River Steamboat Company was originated to run a line of steamers from the Prince's stage to the south end of the borough, and thence across the estuary to New Ferry, and *vice versâ*. Express boats run during the day direct between Liverpool and New Ferry, and others between the south end and New Ferry. This necessitated the erection of a Pier, with landing-stage and connecting bridge at New Ferry, which was constructed from the designs of Mr. Brunlees, by Messrs. W. and J. Galloway and Sons, contractors, under the superintendence of the Author, for Mr. R. A. Macfie, of Liverpool, who leases it to the Mersey River Steamboat Company.

The original slipway was one of the oldest on the river, consisting merely of a bank of clay, raised about 2 feet above the shore, and covered with loose stones. The approach to the new pier, at the shore end, is formed by a curved retaining wall, on which the ends of the first set of girders rest. A wrought-iron railing on the coping of the wall, provided with three carriage gates, each 10 feet wide, and two wicket gates, each 5 feet wide, encloses a space pitched with stone sets, upon which the two pay-boxes and office are placed.

The pier proper consists of fourteen spans, each 58 feet in the clear. It is formed of three lines of wrought-iron girders, placed 9 feet apart from centre to centre, and resting on cast-iron columns. The pier is thus divided into two distinct ways, one of which is used for the up and the other for the down traffic, the girders themselves forming the parapets. The openings are arranged in three groups; the first, from the re-

taining wall towards the river, comprising five bays, then two rows of columns, three in each row, and 4 feet apart from centre to centre measured along the platform; next, four bays, and again two rows of columns; and lastly, five bays, terminated by a platform, 18 feet by 16 feet, supported on a cluster of eighteen columns, securely braced horizontally and vertically, by means of angle irons 3 inches by 3 inches and $\frac{1}{2}$ inch thick. The girders are each 60 feet in length, and 4 feet 9 inches in depth. The top member of the girder is composed of two half round bulb irons, forming, when riveted together through the flanges, a tube of 8 inches external diameter. The remainder of the girder is of the ordinary lattice form. The two footways, each 8 feet 4 inches wide, formed of Memel planking 4 inches thick, are carried on the bottom flanges of the girders, the planks being secured at the ends by bolts $1\frac{1}{2}$ inch in diameter. The two outside girders are each calculated to bear a load of 120 lbs. per superficial foot of platform, and the centre girder is nearly twice the strength of the others. The supporting columns are 12 inches external diameter, the metal being $\frac{3}{4}$ inch thick. They are generally cast in lengths of 10 feet, and are connected by flange joints, excepting the junction of the columns with the piles, which is of the socket form. The piles were cast in variable lengths, to suit the contour of the ground, and are furnished with one turn of a screw at the bottom, 2 feet 6 inches in diameter, the metal being $1\frac{1}{4}$ inch thick at the root. The bottom of each pile is of a plain spigot form. The piles were screwed down to depths of from 6 feet to 10 feet, by means of a capstan head of cast iron, with eight bars 9 feet in length, worked by about thirty men, until an exceedingly hard bed of clay was reached, on entering which about 2 feet, it was found impossible to screw the piles further by hand power. The tops of the piles of each pier were then cut off to a level of about 2 feet above the surface of the shore, and a double false socket was fixed on, by means of a rust joint. Variable lengths of the columns were then cast, in order that the remainder might be used in lengths of 10 feet, and thus insure uniformity in the work. Each pier consists of a line of three cast-iron columns and piles transversely to the footway, and on the top of each column there is a cast-iron bearing plate, 2 feet long, to which the ends of the girders are secured by two bolts, each 1 inch in diameter, the holes in the girders being of an oval form to allow of expansion and contraction. A space of $\frac{1}{2}$ inch is left between the ends of the girders, which is concealed by a light, ornamental iron casting, so arranged as not to interfere with the motion of the girders. In the case of the centre girders, a cast iron lamp standard is added on the top of these coverings. The outside girders are stiffened at the ends over the piers by gusset pieces, bearing on cast-iron brackets, bolted to the heads of the columns on

the outside. Similar brackets are used under the ends of the girders where they bear on the heads of the columns. The gussets are formed of two angle irons, each 2 inches by 2 inches and $\frac{3}{8}$ inch thick, filled in with a $\frac{1}{4}$ inch plate, of a triangular form, the base being 1 foot 9 inches, and the height 4 feet. Throughout the length of the pier, and at intervals of 7 feet 6 inches, the girders are kept apart by transom bars of T iron, 4 inches by 3 inches and $\frac{1}{2}$ inch thick, bolted to the underside of the bottom plates of the girders, by four bolts $\frac{3}{4}$ inch in diameter to each girder.

The outer edge of the platform, at the head of the pier, forms a bearing for the moveable joint at the upper end of the Bridge, connecting the pier with the floating stage (Fig. 2, p. 221). This joint admits of a horizontal and vertical motion of the bridge, and consists of a strong wrought-iron girder, having a radial motion round a steel pin, 4 inches in diameter, fixed to a girder forming a portion of the framework on the top of the columns. The vertical motion is obtained by means of a hinge under each girder of the bridge, composed of a wrought-iron forging, bolted to a rotating girder, and a steel pin, 2 inches in diameter passed through it and the two forged straps riveted round the end of the bridge. The underside of the rotating girder immediately under these hinges is supplied with two sheaves, or rollers, bearing on segments fixed to the heads of the columns.

The bridge is 158 feet in length, and is formed of two bowstring girders, on the lattice principle, 10 feet in depth at the centre. The vertical web consists, for a length of 16 feet from each end, of plates $\frac{1}{4}$ inch thick, the rest of the girder being of the ordinary lattice form. The girders are 9 feet 8 inches apart from centre to centre, leaving a roadway of 8 feet 4 inches in the clear. They are kept apart at the bottom by transoms of T iron, 4 inches by 3 inches and $\frac{1}{2}$ inch thick, at intervals of 16 feet throughout the bridge, each intermediate space being filled in diagonally with two angle irons, 3 inches by 3 inches and $\frac{1}{2}$ inch thick.

The upper members of the girders are kept in place by an arch of wrought iron, 16 inches in depth, the top and bottom being each formed of two angle irons, 4 inches by 3 inches and $\frac{1}{2}$ inch thick, with a vertical plate between them $\frac{1}{2}$ inch thick. The headway from the level of the platform to the underside of this arch at the centre is 13 feet.

The platform of the bridge is composed of planking, 4 inches thick, laid transversely, and secured to the upper side of the bottom plates of the girders by an angle iron, 4 inches by 4 inches and $\frac{1}{2}$ inch thick, running longitudinally and crossing the ends of the planks. This angle iron is bolted at intervals to the flange of the girder, and forms a kerb on each side of the bridge. The surface of the planking is covered with teak, $1\frac{1}{2}$ inch in thickness, grooved

Fig. 1.

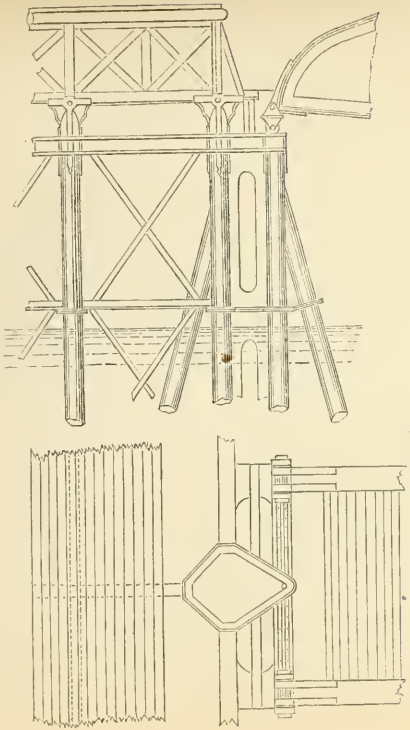


Fig. 2.

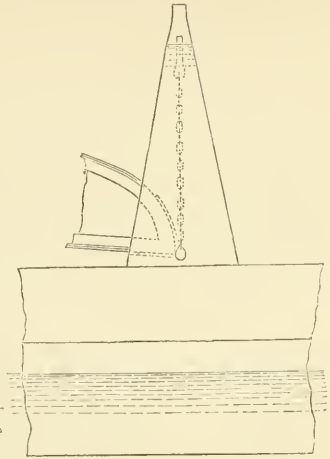
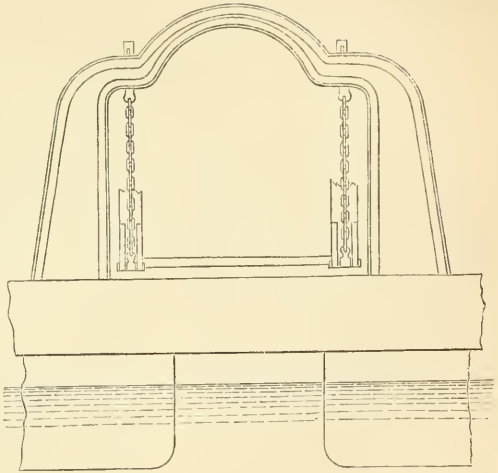


Fig. 3.



Attachment of Moveable Girder to Pier and to Pontoon.

at intervals of about 6 inches throughout, and spiked to the planking. Two longitudinal grooves, with copper scupper holes, allow of the escape of water down the bridge. Hinged flaps of teak are fixed at the top and bottom of the bridge. The lower end of the bridge is suspended by chains 2 inches in diameter from a cradle, formed of wrought-iron plates and angle irons, fixed on the floating stage (Fig. 3). This was considered necessary, to reduce the strain on the pier and bridge, caused by the rolling of the stage, and is found to answer very well. The upper surface of the platform of the pier is 12 feet above high water of ordinary spring tides, or 7 feet above an extraordinary tide of 21 feet above the Old Dock Cill, the datum from which the tides are reckoned in the Mersey.

The Floating Stage is 100 feet in length by 22 feet in breadth, tapering for a length of 19 feet to 19 feet at each end. A spur, 22 feet by 11 feet, projects at the back under the bridge. The depth of the iron pontoon is 7 feet 3 inches, and from the top of the platform to the bottom of the pontoon it is 8 feet 6 inches. The sides have a 'batter' inwards of 1 foot. The pontoon is built of ribs of T iron, 4 inches by 2 inches and $\frac{3}{8}$ inch thick, 1 foot 9 inches apart from centre to centre, fixed transversely to the stage. It is divided into five compartments by four watertight bulkheads, each formed of a frame of two angle irons, 3 inches by 3 inches and $\frac{1}{2}$ inch thick, filled in with plates $\frac{1}{4}$ inch thick, stiffened vertically at intervals of 3 feet by T irons, 4 inches by $2\frac{1}{2}$ inches and $\frac{1}{2}$ inch thick. To increase the stiffness, there is a longitudinal bulkhead of the same construction through the centre of the pontoon, and there are also smaller bulkheads under the cradle supporting the bridge. The skin forming the sides and bottom of the pontoon is of plates $\frac{1}{4}$ inch thick. The deck of the stage is formed of planking 2 inches thick, laid transversely, and spiked to longitudinal timbers, 9 inches by 9 inches, and 3 feet apart from centre to centre, bolted to the ribs of the pontoon; the joints of the planking being caulked to render them water-tight. A nosing of timber, 11 inches by 6 inches, is run round the front and edge of the stage, and below this, along the front, there is hung a timber fender 2 feet by 6 inches. The front of the pontoon is supplied with nine cast-iron mooring studs, each secured to the ironwork of the pontoon by four bolts. Two similar studs are fixed at the back of the stage. A fence runs entirely round the stage, consisting of two lines of chain, $\frac{3}{8}$ inch in diameter, supported by forged wrought-iron stanchions. At the back of the stage there are two landing-places or gangways, one on each side of the bridge, for small boats, approached by means of wooden steps. On the stage two waiting sheds are provided, each 20 feet by 6 feet 6 inches, with all necessary conveniences.

The stage is moored by four chains, $1\frac{3}{4}$ inch in diameter, two at

each end of the pontoon. Each chain is 50 fathoms in length, and at right angles to the adjoining one, the end of each being secured to an anchor with one fluke. Provision is made for taking in the slack of the chains by two sets of gearing fixed on the stage, one at each end, consisting of a worm and worm wheel; one set of gearing taking in the slack of two contiguous chains. The gearing is worked by levers, provided with stoppers, the whole being boxed in with wood to prevent accidents.

A dioptric light, by Messrs. Chance Brothers, of Birmingham, is fixed on the top of the arch forming part of the cradle used for suspending the bridge, access to which is obtained by means of a light wrought-iron gallery and ladder.

Gas and water are supplied from the mains on the shore, by means of pipes laid on the bottom flanges of the outside girders, one on each side of the pier, the water being used for the shipping, and the gas for lighting the pier and stage.

The pontoon draws about 2 feet of water, and at low water of spring tides, there is never less than from 7 feet to 8 feet of water at the front of the stage.

The dimensions of the various parts of the structure are then given in detail; and with regard to the expenditure on the works, it is stated that, the approaches had cost £1,063, the pier (including the bridge) £7,740, and the stage £2,674, making a total of £11,477.

The design for the New Brighton Pier and Landing Stage was of a similar character to that of the New Ferry Pier, and was likewise furnished by Mr. Brunlees, the original contractors being Messrs. Rothwell and Co. The works in the first instance were under the superintendence of the Engineer to the Wallasey Local Board of Health; but an accident having occurred, in the attempt to place the bridge in position, which rendered the construction of a new bridge necessary, the Author was placed in charge. As the Wallasey Board was not satisfied with the state of the works, their completion was finally intrusted to Messrs. Bowdler and Chaffer.

The Pier consists of three lines of wrought-iron girders, each girder being 60 feet in length. There are twelve bays, or spans, divided into three groups of four spans each, by two intermediate rows of three columns, placed 4 feet apart from centre to centre, measured along the pier. The enlarged platform at the river end of the pier, on the outside face of which the upper end of the bridge rests, is 33 feet 6 inches by 16 feet. It is supported by short wrought-iron girders resting upon a cluster of twenty vertical and thirteen raking cast-iron columns, 12 inches external diameter, the metal being $\frac{3}{4}$ inch thick, with screws 2 feet 6 inches in diameter. The cluster of columns

is strengthened by horizontal bracing of angle iron, 3 inches by 3 inches and $\frac{1}{2}$ inch thick, and by vertical bracing of bars, 3 inches by $\frac{1}{2}$ inch, keyed at one end, and the three adjoining piers towards the land are braced vertically by two tiers of the same iron. The fourth double pier from the cluster is braced in the same manner, but in the upper length of 10 feet of the columns only. The other piers are kept apart by transoms of cast iron, 9 inches in depth, fixed in sockets cast on the heads of the columns, and transversely to the line of the pier. The foundations of the cluster of columns and of the two adjoining piers are formed by screw piles, with blades 2 feet in diameter, and having a pitch of 7 inches; they passed through variable depths of from 5 feet to 8 feet of sand and gravel to the surface of the rock underneath. In the case of the remaining piers, discs were cast at the foot of the columns, 2 feet 6 inches in diameter, which are bedded in the rock close to the surface. The width of the pier from centre to centre of the outside girders is 21 feet 4 inches, the centre girder dividing the platform into two footways, each 10 feet in the clear, the girders themselves forming the parapets. The planking of the pier is 3 inches in thickness, supported in the middle under each footway by a longitudinal T iron, 4 inches by $3\frac{1}{2}$ inches and $\frac{1}{2}$ inch thick, bearing on transoms of T iron, connecting the bottoms of the girders at intervals of 7 feet 6 inches throughout the length of the pier. The lamp standards and castings over the ends of the girders are similar to those used at New Ferry.

The Bridge connecting the pier and stage is 160 feet in length. The two girders are 11 feet apart from centre to centre, leaving a clear footway of 10 feet 3 inches. The planking is 4 inches in thickness, and is laid transversely, and this is covered with teak, grooved, $1\frac{1}{2}$ inch in thickness. The upper end of the bridge has a similar motion to, and the lower end is hung from a cradle on the same principle as, that at New Ferry.

The Floating Stage is 200 feet in length by 30 feet in breadth, and consists of a series of twelve pontoons, connected by three lines of lattice girders, each 2 feet 3 inches in depth, and two lines of box keelsons, each 3 feet in depth and 2 feet 9 inches in width, formed of two angle irons at the top, each 6 inches by 6 inches and $\frac{5}{8}$ inch thick, the vertical plates being $\frac{5}{16}$ inch thick. The horizontal plates are two in number throughout, both at the top and bottom, the two lengths of 43 feet 6 inches from each end being $\frac{3}{8}$ inch thick; the next two lengths of 32 feet 6 inches being $\frac{5}{8}$ inch thick, and the centre length of 31 feet being $\frac{3}{4}$ inch thick. Wrought-iron bars, formed of angle iron, 6 inches by 6 inches and $\frac{3}{4}$ inch thick, are riveted to the top edge of the pontoons, and the bottom flanges of the longitudinal keelsons are bolted to them. The end pontoons are pointed so as to act as cutwaters, and are

each 29 feet by 18 feet; the ten intermediate pontoons are 29 feet by 11 feet 6 inches, and the depth of all the pontoons is 6 feet 3 inches. The pontoons are formed of a framework of ribs of T iron, $3\frac{1}{2}$ inches by 2 inches and $\frac{3}{8}$ inch thick, and 1 foot 7 inches apart from centre to centre, with a bulkhead at the centre; the top plates are $\frac{3}{16}$ inch thick, and the sides and bottom $\frac{1}{4}$ inch thick. Each pontoon is provided with an oval manhole, with water-tight cover. On the top of the longitudinal girders, timber joists are laid transversely, 2 feet apart from centre to centre, the scantling being 9 inches by 6 inches at each end, and 12 inches by 6 inches in the centre, thus giving a camber of 3 inches from the centre of the deck to the edges. The deck is formed of planking, $2\frac{1}{2}$ inches thick, running lengthways of the stage, the joints being caulked and run with pitch. Round the edge of the stage, on the top of and flush with the sides of the pontoons, are two timbers, 12 inches by 12 inches; and planking 6 inches in thickness, sheathed with wrought-iron plates $\frac{3}{16}$ inch thick, is fixed vertically to these timbers, by spikes 10 inches long. In front of the stage there is a hanging fender, 2 feet by 9 inches, suspended by chains from the mooring studs. A fence formed of two lines of $\frac{3}{8}$ inch chain runs round the stage, the stanchions being of forged iron, 6 feet 6 inches apart, and the whole galvanized. There are two waiting sheds of timber on the stage, each 40 feet by 10 feet, provided with all necessary conveniences. The stage is moored at the ends by two chains, 50 fathoms in length and $1\frac{3}{4}$ inch in diameter, at right angles to each other, and in the river they are attached to cast-iron mushrooms, 5 feet in diameter. At the back of the stage are four breast chains, $1\frac{1}{2}$ inch in diameter, fixed to mushrooms on the shore.

The dimensions of the several parts of the structure are then given in detail; and in conclusion it is stated that the total cost of the pier, bridge, stage and subsidiary works, has amounted to £23,906.

The communication is accompanied by a series of diagrams, from which the woodcuts, Figs. 1, 2, and 3, have been engraved.

Mr. Brunlees said the only explanation he had to offer was in respect of the cost of the two piers. It would have been noticed that the cost of one pier was almost double that of the other, although the designs in both cases were similar, and the difference in cost ought not to have been more than about £2,000. In explanation he stated that New Ferry Pier was built for one proprietor; and in that case Mr. Brunlees was permitted to appoint his own Resident Engineer, and was fortunate in having a good contractor. The New Brighton Pier was under the superintendence of a Board, who appointed their own Resident Engineer, and were very unfortunate in their contractor.

Mr. Haughton thought it might add to the interest of the subject if he referred to a disastrous event which occurred to the New Brighton Pier in the autumn of 1867, and which he witnessed. While fully appreciating the great ingenuity of the design, and the extreme simplicity of the whole structure, it seemed to him, previous to the event alluded to, that the landing-stage was in a very unprotected state. One day while waiting for the ferry-boat to Liverpool, he noticed a screw steamer, the 'Galileo,' coming down the river, apparently outward bound. After a time her helm was put a-starboard, and an endeavour was made to anchor her in the centre of the river, by wheeling in a semicircle so as to place her head to the tide. A strong south-east wind was blowing, and in making this manœuvre, the pilot miscalculated the force of the wind, and the vessel would have gone ashore to the northward of the pier, had the pilot not placed her alongside the landing-stage—the best thing under the circumstances that could be done to insure the safety of the ship, which was ultimately accomplished. It struck Mr. Haughton that the bridge was in serious peril. The pilot then put the vessel ahead under full steam; but she had not proceeded more than about 50 yards from the landing stage, when the strong wind, catching the ship on the port bow, blew her across the head of the stage, and after a time the pressure became so great, that the moorings yielded, the bridge curled up in the air like a sapling, and fell in three fragments into the water. The landward end of the bridge was torn from its connection; but the riverward end retained its attachment to the arch by means of the chains, until some one on the landing-stage cut it loose with a chisel and let it go 'by the board.' The bridge had since been renewed, and now rested on the landing stage on a series of rollers set in a frame.

Mr. Bramwell said, with regard to the accident that befell one of these structures, it had not been suggested that anything ought to have been done by the Engineer which had not been done. A very large steamer, such as was never intended even to come alongside, to avoid being driven on shore, not only came alongside,

but actually into collision. Mr. Bramwell did not think, from what he had heard, that the designer of this pier would have been justified in providing means for resisting an extraordinary occurrence of that kind; and in corroboration it appeared that those who reconstructed the work had not taken any extra precautions against a similar accident. It seemed that the connections of the bridge were more than sufficient for all ordinary purposes, and that they were not even injured by the collision. Mr. Brunlees, therefore, might be congratulated on having made an efficient, but inexpensive pier; and probably the captain of the steamer, revolving in his mind the value of his vessel, in comparison with that of a pier which should have cost only £10,000, did the best thing he could in running into something cheap.

Mr. Bazalgette said it was satisfactory to him to observe that, in their general features, these works were much the same as he had adopted in the construction of the landing stages of the Thames Embankment. The main difference appeared to be that the pontoons of the New Ferry and the New Brighton landing stages were carried out from the shore into deep water, and were so arranged that vessels could come alongside; while in his case the Embankment had been carried into deep water, and the object was to construct the piers so as not to project, or in any way to impede the navigation of the river. Consequently, in those now constructed on the Thames, the bridges, instead of being at right angles to the shore, were parallel to the roadway, and were masked behind a wall. Again, the pontoons were placed in recesses, and kept in position by iron guides fixed in the masonry. In adopting that mode of construction, it had occurred to him as possible, that deposit might take place under the pontoons. To obviate that, arches had been built under the Embankment, into which the tide was allowed to flow at high water, and within which it was retained by means of penstocks; so that on the penstocks being raised at low water, the bed of the recess was flushed out, and the deposit which had accumulated under the pontoons was cleared away. He was not prepared to compare the size and cost of the Embankment pontoons with those described in the Paper. In the arrangement he had adopted, the bridges were necessarily placed upon one side of the pontoon; the effect of this was to cast the pontoon over towards the shore, and in consequence it had been necessary to load the pontoons on the other side, to make them balance. He thought it would be advisable in future, under similar circumstances, to construct the bridges of steel, rather than of iron, and thus to make them much lighter. The pontoons were reduced in cost by utilizing the caissons which had been previously used to form the coffer-dam in the construction of the Embankment. These caissons were the ground-

work of the pontoons; and by that means considerable economy had been effected.

Mr. G. H. Phipps asked whether, in this mode of construction, any weakness was found to result from the twisting action of the separate pontoons, caused by the action of the waves at each end of the pontoon?

Mr. Brunlees replied, that this was provided against by strong keelsons running from one end to the other of the pontoons.

Mr. Grover wished to ask one or two questions, as he had found some difficulties in carrying out works of a similar character. In the first place he would inquire if any of the piles had been broken in the process of screwing into the ground, and if any observations had been made as to the effect of salt water upon iron piles in general. He believed that considerable difference of opinion still existed, as to whether it was advisable to use cast or wrought iron. In a pier he was executing on the Thames, at Woolwich Arsenal, he decided to use wrought-iron cylinders in preference to cast-iron columns. He believed the iron, whether wrought or cast, usually failed at those points where the bolts passed through the flanges. Galvanic action he presumed took place at those points, and rapid decay of both bolts and flanges followed; so that, practically, the durability of the structure was to be measured by the durability of the bolts. He should like to be informed, whether any protecting material was used for preventing the action of the water upon the piles in the Mersey, and whether the interior was filled up. In the Clevedon pier he had filled the piles with a solution of coal-tar, lime, and sand, poured in at the top. In the work which he was carrying out at Woolwich Arsenal the wrought-iron cylinders were coated with a solution of coal-tar, naphtha, and resin. This he considered should be done just before immersion, for if rust was once allowed to set in, neither coal-tar nor any other application would be of any avail. The cylinders were afterwards filled in with concrete.

Mr. Beardmore remarked, with regard to the piers at Liverpool, that there was always a gentle rolling movement, with a strong breeze and a counter-tide in the Mersey, and in heavy weather it was very sensible; but the longitudinal keelsons kept the pontoons together, so as to a great extent to distribute the effects of the waves. The most troublesome thing hitherto on the Thames had been the ice, which, in severe winters, accumulated beneath the pontoons to such an extent as to endanger their safety. He much feared that the new landing stages on the Thames would be in some peril from the same cause, from the peculiar recesses in the Embankment within which the pontoons were placed. With regard to the question of the decay of iron in works of this kind, there was nothing to be feared, under ordi-

nary circumstances when reasonable care was taken. There had recently come under his notice, the case of a sea lock, which had existed for thirty five years at the head of a ship canal containing very soft water. When pumped out for repairs, it was found that all the cast and wrought iron portions of the gates, &c., were equally destroyed. Even the spikes of the platform planking were perished, though the timber was perfectly sound. He attributed that intense action of the water upon the iron to the mixture of fresh and salt water, to which the lock was peculiarly subjected, as the soft water was 'locked' down direct into the saltest of sea water. Cast and wrought iron similarly exposed, and for the same length of time, in the Thames would be scarcely affected, probably from the absence of the mixture of salt water.

Mr. HEMANS inquired whether any inconvenience was found in having the pontoons which supported the landing stages at right angles to the current. It appeared to him that if thick ice or floating timber got lodged between the pontoons considerable inconvenience might result. It would be a simple matter to connect the ends of the pontoons, so as to make a flush side, like that of a ship, along which the water would flow without interruption.

Mr. MALLET remarked, as to the amount of movement of the large landing stages on the Mersey, that several years ago, during a strong winter gale, when the waves were probably from 5 feet to 6 feet in height in the estuary, he had ascertained, from rough personal observation, that the twisting or buckling of the floor of the St. George's Pier landing stage, which had been constructed from the designs of the late Sir W. Cubitt, was about 5 inches. The general question of the durability of iron was a very important one, and he could not then venture to enlarge upon the subject of the corrosion of iron, to which he had devoted a good deal of attention. Briefly, he would say that the result of observation induced him to consider wrought iron was, upon the whole, a more durable material than cast iron. It was true that some wrought iron corroded faster, but only a little faster, than some cast iron; but the amount of decay, and the rate of weakening, could be ascertained by measurement in the former, whereas in cast iron the nature of the corrosion was entirely different, and the mass of the material suffered a molecular and chemical change to a considerable and uncertain depth. In sea water, especially if mixed occasionally with well aërated fresh water, there was the maximum rapidity of corrosion, both of wrought and of cast iron, except that producible by the admixture with sewage water, which often contained matter that corroded iron almost as fast as diluted vitriol. The protection produced by even a thin film of mud, covering up immersed iron, so as to screen it from fresh supplies of

water unexhausted of its combined air, had a marvellous effect in preserving it. With regard to artificial modes of preservation by various coatings, in his opinion there was nothing equal to coal tar, well boiled, with a mixture of finely-powdered dry caustic lime. The iron to be coated should be previously heated to about 600° or 700° Fahrenheit, and be dipped into the mixture. It was useless merely to pay over cold iron with coal-tar, as was often done; the iron must be heated almost to a black red, be immersed for some time in the hot tar, which then perfectly dried upon it, and produced a varnish almost as persistent as the japan on a tea-tray. If the iron were previously painted with oil-paint, the coal-tar would not adhere, nor become hard and dry upon it.

Mr. Redman mentioned, with reference to the decay of iron structures exposed to the action of salt or brackish water, that in the estuary of the Thames, there were several works which had been completed from twenty to twenty five years, where the pillars were of cast iron, and which yet remained intact at the present time. The pier at Milton-on-Thames, below Gravesend, designed and carried out by him in 1842-44, was supported on cast-iron columns, 3 feet in diameter, the metal being $1\frac{1}{2}$ inch thick, and these were unaffected by such action. The Gravesend Town Pier, by the late Mr. Tierney Clark, M. Inst. C.E., was on similar supports, the metal being $1\frac{1}{4}$ inch thick; and these too, though about thirty years old, were similarly unaffected. The cast-iron columns of the Maplin Sand Lighthouse, erected about the same time, likewise remained sound, although the metal was only $\frac{3}{4}$ inch thick.

Mr. Brunlees said, in reply to the observations as to the unprotected state of the pontoon at New Brighton, that in the original design he proposed to construct dolphins at each end for the protection of the pontoons; but Admiral Evans, the Conservator of the River Mersey, would not allow this to be done. Hence the alleged unprotected state of the pontoons. In reference to the durability of cast iron in salt water, so far as these piers were concerned, the time had been too short to form any opinion upon it. But he might state, with regard to the viaducts which had existed in Morecambe Bay for fifteen or sixteen years, that there was not at this time any sensible decay in the iron columns there. The whole of the cast iron work in these structures was protected with a preparation of tar and asphalte. The tar was heated in a large tank, and each piece of ironwork was boiled in that preparation for half an hour; this he believed was the best protection for cast iron. With reference to the interior of the piles, his practice had been to fill them in simply with clean sand, and by that means he found the water was excluded from the inside of the piles. If the water were not excluded, in frosty weather

the columns would be apt to burst. As to the anchors, those used were so large and efficacious that hitherto none of them had dragged. There was not the slightest risk of ice, or other material, getting into the spaces between the pontoons, because a rubbing piece was placed at the water-level all round the stage. He could not agree in the opinion that wrought iron was preferable to cast iron for use in sea-water, inasmuch as in order to bring down the cost to the same as cast iron, it would be necessary to employ wrought iron so thin that it might be more liable to waste away and to be affected by mechanical injury. He believed the decay of cast iron was not so rapid as that of wrought iron, and that it was a safer and more reliable material.

Mr. Mallet explained, that he did not say anything as to the choice between wrought and cast iron as applied to piers in water, or other like structures; nor did he wish it to be inferred, that in all such cases he preferred wrought iron to cast iron. He referred simply to the relative durability of the two materials in respect to aqueous corrosion, and to the character of that change in each. But many other considerations besides corrosion must enter into the engineer's consideration as to the material for piles, piers, &c., in or out of water. And so far from being prepared indiscriminately to employ wrought iron, he should, until it could be manufactured into hollow piles, in forms much cheaper than were at present possible, endorse the use of cast iron, as adopted by Mr. Brunlees. The question of durability in cast iron resolved itself, as regarded cost, into one of so much increased thickness at the outset as amply to allow for it in reference to a predetermined period of endurance.

February 2, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—Joseph Haywood Watson Buck, Thomas Dale, Peter Greck, and Henry Johnston Wylie, as Members; John Bowden, Alfred Mountain Fowler, Charles Hart, Bleamire Moody de Michele, Joseph Musgrave, Eyre William Preston, Alfred Louis Sacré, Harco Theodorus Hora Siccama, Augustus Horace Strongitharm, and Joseph William Wilson, as Associates.

It was announced that the following Candidate, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye Laws, as Student of the Institution:—Joseph Pomfret van der Meulen.

No. 1,202.—"The Mauritius Railways—Midland Line." By James Robert Mosse, M. Inst. C.E.[1]

The chief object of this Paper is to give a concise account of the working of the unusually heavy gradients which prevail on the Midland Railway. Before, however, proceeding to this subject, it may be well to notice, briefly, the chief physical features of the island, and the causes which led to the introduction of railways in the colony.

Mauritius is entirely of volcanic origin. The mountains consist of basalt, tufaceous rock, and lava, and have been thrown up on all sides to heights varying from 2,000 feet to 3,000 feet above the sea. In the centre of the island, the table-land traversed by the Midland Railway has an elevation of 2,000 feet above the sea, the distance from the coast being about 15 miles. In the northern and eastern parts, the ground rises gradually; but in the southern and south-western portions, the features of the country are exceedingly broken and rugged.

The soil of Mauritius, though unusually fertile, varies greatly in character. In some places and for a considerable area, the soil is deep and entirely free from rocks; while within a short distance, the rock again crops out on the surface without any soil whatever.

[1] The discussion upon this Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

Throughout a large portion of the island the soil is covered with loose blocks of basalt and lava of all sizes, which are piled up into parallel rows, 5 feet or 6 feet apart, and the canes are planted between them.

The extreme dimensions of the island are about 38 miles long by 37 miles broad. Its area is about 706 square miles, of which there are under—

Cane cultivation	230	square miles.
Planted with maize, manioc, and vegetables	25	,,
Forest and pasture	168	,,
Waste and uncultivated land	283	,,
Total	706	,,

For so small an area, the population of Mauritius is extraordinary. According to the returns made on the 31st December, 1866, the population of the colony then amounted to 341,165, of which about 75,000 resided in Port Louis, the principal port and the seat of Government. The population thus amounts to 483 per square mile over the whole island, or to 1,338 per square mile over the land in cultivation.

Sugar-cane is well known to be the principal, it may almost be said to be the only, production of Mauritius. With this exception the colony raises scarcely anything required for its consumption, but exports nearly its whole product, and imports all articles required for food and for its other necessities. Everything grown in the country is sent to Port Louis for exportation, and everything required on the estates is brought back from that town; hence arises an amount of traffic between the port and the interior unusually great in proportion to the population and to the area of the country.

For the last seven years the average imports into and exports of sugar from the Mauritius have been as follows:—

	Tons.	Value.
Imports	279,597	£2,131,408
Sugar exported	126,852	2,206,196
Total exports	215,811	2,375,230

From these figures the following results are obtained:—

Per Square Mile per Annum.

	Tons.	Value.
Imports	396	£3,019
Total exports	306	3,364

Per Head per Annum.

	Ton.	Value.
Imports	0·81	£6·25
Total exports	0·63	6·93

From 1860 to 1866 the average population has been 326,214, the revenue £571,931, and the expenditure £578,969, giving £810

and £820 per square mile per annum respectively, or £1·74 and £1·76 per head per annum.

From the hilly nature of the island, from the expense of importing mules from France and Montevideo, grain from India, and oats from Australia or the Cape, it will be evident that the best means of conveying these exports to town, and the imports from Port Louis to the interior, soon became a serious question.

Until recently, the sugar from the estates near the coast was conveyed to Port Louis by schooners, carrying from 60 tons to 120 tons each, and from the other parts of the island it was carted to town by mules. These carts conveyed from 30 cwt. to 40 cwt. of sugar each, and required three and sometimes four mules; but in ascending from Port Louis to the districts traversed by the Midland Line, the return load only ranged from 10 cwt. to 15 cwt. per cart. Conveyance by coasters, though cheap, depreciated the sugar, owing to its exposure to the damp, and to the losses consequent on frequent transhipments and pillage; while the cartage was, for the reasons given, very expensive, notwithstanding the excellent condition in which the roads are maintained by the Government.

The necessity for railway communication being felt by the local Government, Mr. James A. Longridge (M. Inst. C.E.) was in May, 1858, charged by the Right Hon. the Secretary of State for the Colonies, "to investigate by regular surveys and sections, and by careful estimates, complete as to outlay of capital, annual expenditure and traffic returns, the question as yet undecided of the introduction of railways into Mauritius." The Report being in favour of the railway system, the construction of the works was, in May, 1861, authorised by the Imperial Government. For some time hopes were entertained that the railways would be undertaken by a private Company; but, as no suitable offer was made, it was decided that the works should be carried out by the local Government, the funds being obtained from some large balances of revenue then on hand, and by the issue of one million pounds of colonial debentures, bearing 6 per cent. interest, and secured by a sinking fund. The total sum for which the general revenue of the colony thus became responsible was £78,000 per annum. Mr. Hawkshaw (Past-President, Inst. C.E.), who had previously reported on the railways by order of Government, was appointed Consulting Engineer to the Mauritius Government; and in September, 1861, a contract was entered into with Messrs. Brassey and Wythes for the execution of the works, which were commenced early in 1862, under the direction of Mr. Walmsley Stanley (M. Inst. C.E.), as Chief Resident Engineer for the Government, and of Mr. J. A. Longridge (M. Inst. C.E.), as Agent for the Contractors.

The North Line, starting from the central station at Port Louis,

traverses the northern and the north-eastern parts of the island, through the districts of Pamplemousses, Rivière du Rempart, and Flacq to Grand River, being a distance of 31 miles. The Midland Line, commencing at the same station in Port Louis, passes through the centre of the island, by the districts of Plaines Wilhems and Grand Port to Mahebourg, a small town containing a population of about 6,000, and distant 35 miles from Port Louis.

The North Line contains no engineering feature of interest, and the only work of importance on the Midland Line is the Grand River Viaduct, already described in Mr. Ridley's Paper.[1] The North Line was opened for public traffic on the 24th May, 1864, and the Midland Line on the 19th October, 1865.

Sufficient land has been purchased for a double line, and the masonry of all culverts and bridges has been built for a double way; but the ironwork for the superstructure of the under girder bridges and the permanent way have only been provided for a single line of rails.

The rails, which are laid to the ordinary narrow gauge, are of the usual double-headed pattern, weighing 74 lbs. per yard, fished with plates weighing 11 lbs. each, the sleepers being placed 2 feet apart from centre to centre at the joints, but averaging 1 yard.

The chairs are of the usual form, weighing 25 lbs. each, but countersunk at the bottom for a length of 2 inches by 2 inches in width, and by $1\frac{1}{4}$ inch in depth. These chairs have not proved sufficiently strong, quantities having broken through the hollow in the bed, where the metal is about $\frac{7}{8}$ inch thick; so much so that the chairs now ordered to replace them are made of increased strength. The keys have held well; the climate being wet in the hot season, they have not shrunk so as to get loose, nor have they swollen so as to break the lip of the chair.

The sleepers are of Baltic red timber, 9 feet long by 10 inches by 5 inches in section, creosoted with 1 gallon of oil to every cubic foot of timber. Some miles of these sleepers have now been in use five years, and few, if any, show signs of decay; nor have they been in the least attacked by the white ants, which destroy all ordinary timber in damp situations, except teak, in the course of two or three years. It should be mentioned that the ballast is composed entirely of broken stone, which keeps the sleepers more than usually dry, and in order to prevent their splitting from the heat of the sun, they are covered with ballast to a depth of 3 inches or 4 inches. The rigidity of this stone ballast may, probably, in some measure, account for the large breakage of the chairs before alluded to.

The cost of these railways may be taken as follows:

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. xxv., p. 237.

	£.
Contracts	1,038,641
Extra works	22,927
Central Station, Port Louis	40,230
Purchase of land	195,544
Engineering and management	104,084
Electric Telegraph	6,046
Additional rolling-stock	36,380
Total	£1,443,852

Equal to £21,876 per mile.

For this large expenditure there are many exceptional causes, among others the construction of the line over the Trou Fanfaron, and along the streets of Port Louis to the Caudan, which involved a heavy viaduct and the purchase of valuable town property. The ground also at the Central Station being exceedingly soft, extensive piling was required for the foundations of the masonry and of the turn-tables, &c.

The high charge of £104,084 for management, includes all the expenses connected with the loan, as well as the premium of exchange in remitting the funds thus raised from England to the colony.

The unusually heavy character of the Gradients on the Midland Line will be understood from the following summary:—From Port Louis to the summit, at Curepipe, there is a rise of 1,817 feet, the distance being about 16 miles, which gives an average gradient of 1 in 46·68; and from the summit to the terminus at Mahebourg, a distance of about 19 miles, there is a descent at the rate of 1 in 55·61. For about 12½ miles before reaching the summit, between Coromandel and Curepipe, the inclination is on an average 1 in 41·17; and thence between the summit and Union Vale, for about 13½ miles, the line falls on an average 1 in 45·06.

The following tabular statement will show these gradients more clearly:—

From.	To.	Length in Feet.	Rise in Feet.	Average Gradient 1 in.	Total Rise above Port Louis in feet.
Port Louis	Coromandel	14,800	170	87	170
Coromandel	Rose Hill	28,399	748	38	918
Rose Hill	Phœnix	18,670	388	48	1,306
Phœnix	Vacoa	6,200	60	103	1,366
Vacoa	Curepipe	13,963	437	32	1,803
Curepipe	Summit	2,809	14	200	1,817
			Fall in feet		
Summit	Cluny	33,063	819	40	998
Cluny	Rose Belle	12,124	126	96	872
Rose Belle	Union Vale	25,557	625	41	247
Union Vale	32nd Mile	12,210	180	67	67
					Total Fall.
32nd Mile	Mahebourg	18,116	67⅓	268	0·5
	Total	185,902			

The gradients vary in ascending to the summit from 1 in 27 to 1 in 60, having between these limits a length of 57,362 feet, and a rise of 1,622 feet. In descending towards Mahebourg the gradients vary from 1 in 30 to 1 in 60, having between these limits a length of 57,805 feet and a fall of 1,556 feet. The steepest gradient is 1 in 27, of which there is an aggregate length of 13,526 feet, with a rise of 499 feet, the greatest continuous length of this gradient being 6,163 feet, and the next longest 5,016 feet. The next in severity is 1 in 30, of which there is an aggregate length of 9,526 feet in ascending, and 7,510 feet in descending, the greatest continuous length being 3,000 feet, and four other lengths averaging about 2,400 feet each. After 1 in 27, the gradient of the greatest aggregate length is 1 in 40, equal to 11,460 feet in ascending, and to 8,967 feet in descending, the greatest continuous length being 4,817 feet, the next in length 3,700 feet, with six other lengths of about 1,700 feet each. Of gradients of 1 in 40 to 1 in 50 there is an aggregate length of 9,050 feet in ascending, and 11,974 feet in descending, the greatest continuous length being 5,300 feet of 1 in 44, with four other lengths of about 2,200 feet each within these limits. Of gradients of 1 in 50 to 1 in 60 there is an aggregate length of 6,900 feet in ascending, and 6,100 feet in descending, the greatest continuous length being 3,300 feet of 1 in 50, with two other lengths averaging 2,000 feet within these limits.

The Curves vary from 950 feet radius to 6,000 feet radius, and the lengths of the curves range from 200 feet to 3,200 feet. The ordinary radii are generally from 2,000 feet to 3,000 feet. The following summary shows the least radii which occur on the steepest gradients between Port Louis and Curepipe:—

Radius in feet.	Length of Curve in feet.	Gradient on which Curve occurs.
1,400	1,350	1 in 100
1,500	1,600	1 in 55
1,600	900	1 in 27
1,600	860	1 in 29
1,600	1,930	1 in 30
2,000	1,000	1 in 27
2,000	950	1 in 27*
2,000	970	1 in 27*
2,000	700	1 in 27
2,200	550	1 in 27
2,000	1,300	1 in 30
2,000	700	1 in 30
2,200	600	1 in 27
2,400	1,000	1 in 27

* Reversed curve.

It will thus be seen that 1,600 feet is the sharpest radius which

occurs on the steepest gradients of 1 in 27 and 1 in 30, the greatest continuous length of this curve being 900 feet on the former gradient and 1,930 feet on the latter. The next radius in severity is 2,000 feet on the maximum gradient of 1 in 27, the greatest continuous length of this curve being 1,000 feet. At Beau-Bassin reverse curves of this radius, 1,920 feet in length, are also found on the maximum inclination of 1 in 27. On descending from Curepipe to Mahebourg, the line from the 17th to the 19th mile may be said to be composed wholly of reversed curves, of which the following are some of the chief instances:—

Radius in feet.	Length of Curve in feet.	Gradient on which Curve occurs.
1,300	1,100	1 in 31
1,800	450	1 in 30
1,800	550	1 in 31
1,800	1,700	1 in 36*
1,800	950	1 in 44
1,800	160	1 in 44
1,800	400	1 in 44
1,930	1,000	1 in 30
2,000	800	1 in 31

* Chiefly.

These 2 miles are considered to be the worst part of the railway to work: for, although the gradients are not so steep as elsewhere, the line is altogether curved, and, passing through woods, it is impossible to see for more than a short distance ahead. The most severe curvature between the 19th mile and Mahebourg is at the 29th mile, where the radius is only 1,400 feet, the length of this curve being 1,980 feet, chiefly on a gradient of 1 in 30. Of curves under 2,000 feet radius there is an aggregate length of 21,165 feet; of those ranging from 2,000 feet to 4,000 feet radius there is a length of 49,710 feet; and of curves from 4,000 feet to 6,000 feet (the greatest radius) there is an aggregate length of 25,560 feet, the total length of curves being 96,435 feet, and of the straight portions of the line 89,467 feet.

The Locomotives furnished under the original contract for working these inclines are seven in number, and of the following description: they are tank engines, having cylinders 16 inches in diameter, with a length of stroke of 22 inches; the wheels, six in number, are 3 feet 6 inches in diameter, and are all coupled, the length of the wheel base being 15 feet. When supplied with water and fuel, these engines weigh nearly 37 tons, and they are worked with a pressure of steam of 120 lbs. per square inch. The load which these engines are able to convey depends greatly upon the state of the rails; for though there are sand-pipes leading to four

wheels out of the six, it is always found that the engines work the best when the rail is perfectly dry.

The original engines having been found inadequate for the traffic, subsequently six larger saddle-tank locomotives were designed by Mr. Hawkshaw, of the following dimensions: Cylinders 18 inches in diameter, with a length of stroke of 24 inches; the wheels, eight in number, are 4 feet in diameter, and are all coupled, the length of the wheel base being 15 feet 6 inches. When supplied with water and fuel, these engines weigh nearly 48 tons, and they are worked with a pressure of steam of 120 lbs. per square inch. The centre pairs of wheels (one of which is the driving pair) are fixed stiff in the frame; but in order to pass easily round the curves, both the leading and the trailing wheels have a play of $\frac{3}{4}$ inch in each journal; and the joints of the coupling rods, connecting these wheels with the driving pair, are fitted with a ball and socket, so as to allow the requisite motion. Four sand-boxes are attached to the engine-frame, leading sand to every wheel; but although the sand is of the sharpest quality, obtained specially from the Cape, it is often found impossible to prevent the locomotives from slipping to a serious extent on the steepest inclines. So much is this the case with the first morning goods train, when the rails are wet with dew, that it has been found necessary to extend the time between Port Louis and Phœnix, a distance of 12 miles, from 1 h. 15 m. to 1 h. 30 m., or to a speed, including stoppages, of only 8 miles per hour.

All the engines were manufactured by Messrs. Sharp, Stewart, and Co., of Manchester, and work very satisfactorily. The carriages and wagons are all of the best description, similar to those used in England, and were manufactured by Messrs. Brown, Marshall, and Co., of Birmingham, the wheels and axles having been supplied by Messrs. Lloyd, Foster, and Co., of Wednesbury.

There are two Passenger Trains each way daily between Port Louis and Mahebourg, and two additional trains each way daily between Port Louis and Curepipe, the great majority of first-class passengers residing between these points, and travelling, as season-ticket holders, to town and back daily. There are also two through Goods Trains each way daily, and occasionally special Goods Trains when required for that traffic.

The ordinary passenger train consists of four carriages and the break-van. The smaller engines can fairly take another carriage, making six vehicles in all, say equal to a load of 42 tons, and this is as much as can be depended upon, though on many occasions they have hauled seven loaded vehicles, and in some instances eight, weighing in all about 56 tons.

With goods trains the ordinary number is six loaded wagons plus the break-van, say equal to 70 tons; but with the 5·45 A.M.

down-train, when the rails are wet, the load (in order not to detain the other trains) is limited to five wagons, making six vehicles in all, or say 60 tons. These may appear very small loads for engines weighing 37 tons, but it should be remembered that to ascend gradients of 1 in 30 requires fully eight times the tractive force that would be requisite on a level.

The larger locomotives, weighing 48 tons each, will take five passenger-carriages and one break-van, equal to a load of 42 tons, though on some occasions they have hauled eight loaded vehicles, weighing in all about 56 tons. With goods trains, the ordinary load in descending is nine loaded wagons and a van, say equal to 100 tons, though occasionally there have been twelve loaded vehicles, or, say, about 120 tons. By reducing the lead of the slide-valves to one-eighth of an inch, the power of the engines was subsequently increased 10 per cent.

Deducting stoppages, the running speed of the Passenger Trains is about 16 miles per hour, or, including seven stoppages, 12 miles per hour, between Port Louis and Curepipe, where the gradient for the whole distance rises on the average 1 in 45·83; and 15 miles per hour, including four stoppages, from Mahebourg to Curepipe, where for 19 miles the ascending gradient averages 1 in 55·61. This speed is quite as much as can be realized in ascending in ordinary weather. On wet days, notwithstanding all that can be done with sand, the engines slip; and in many cases, on gradients of 1 in 27 and 1 in 30, with the smaller locomotives, the speed has fallen to 4 miles per hour, even with a train of five vehicles, or, say, of 35 tons.

The average running speed of the Goods Trains is 12 miles per hour, or, including the frequent stoppages, about 9 miles per hour; and this, as the engines are always loaded to their maximum, is as much as can be attained. Speed over these gradients is of less importance than economy of motive power.

Whenever two locomotives are required with any train, either Passenger or Goods, the second engine is placed in the rear of the train, to ease the great strain on the couplings, and control the vehicles, should any of them break loose. This plan, though open to some objections, has hitherto worked well, and there has been no instance in which the vehicles have mounted the rails in consequence of the pushing from behind.

According to the usual formula, the tractive force required per ton, on a curved line with a gradient of 1 in 27, at a running speed of 6 miles per hour, is found to be 95 lbs. With a load of 100 tons, or, including the engine, of 148 tons in all, 6 miles per hour may be taken as the average speed up 1 in 27. Then,

$$\frac{\text{lbs.} \quad \text{tons.} \quad \text{miles.}}{95 \times 148 \times 6 \times 88} = 225 \text{ H.P. exerted, or, excluding the weight}$$
$$33{,}000$$

of the locomotive, it is equal to 152 H. P., and this divided by the weight of the engine becomes 3·16 H. P. per ton of motor. To obtain this tractive force (14,060 lbs.) an effective pressure in the cylinder of nearly 87 lbs. per square inch is requisite; but as 60 lbs. is nearer the average pressure, the tractive force becomes

$$\frac{4 \times 2^{\text{ft.}} \times 60^{\text{lbs.}} \times 254{\cdot}47^{\text{sq. in.}}}{12{\cdot}566 \text{ feet.}} = 9{,}720 \text{ lbs.}$$

In the former case the adhesion required would be 13 per cent., and in the latter 9 per cent. of the weight of the locomotive. Taking the average gradient from Port Louis to Curepipe at 1 in 45·83, the mean tractive force required is 60 lbs. per ton, equal to a force of 8,880 lbs. for a load of 148 tons.

The following are the results of a particular trip made on the 12th December, 1867, when the fuel and water were noted more accurately than usual: The distance from Port Louis to Curepipe is 15·65 miles, in which there is a rise of 1,803 feet. The train consisted of ten loaded wagons, weighing 83 tons, and of an engine weighing 48 tons, together 131 tons. The running time was 1 hour 25 minutes, and the average speed 11 miles per hour. The coal consumed on the trip amounted to 986 lbs., giving 63 lbs. per mile, exclusive of lighting, and 0·48 lb. per ton per mile including the weight of the locomotive, and 0·76 lbs. per ton per mile, excluding the weight of the locomotive. This consumption was at the rate of 696 lbs. per hour, of 39 lbs. per square foot of grate per hour, and of 4·75 lbs. per H.P. exerted per hour. The total water evaporated on the trip weighed 7,888 lbs., so that 8 lbs. of water were evaporated by 1 lb. of coal. The quantity evaporated per hour was 5,568 lbs., giving 309 lbs. per square foot of grate area, and 4·6 lbs. per hour per square foot of heating surface, and 38 lbs. per H.P. exerted per hour. The gross weight of this train being 131 tons, the average power exerted would be

$$\frac{131 \times 60 \times 11 \times 88}{33{,}000} = 230 \text{ H.P.},$$

or, not including the weight of the engine, 146 H.P., and this divided by the weight of the locomotive is equal to 3·04 H.P. per ton of motor. The coal used on this trip was obtained from the Warattah Colliery, near Sydney, New South Wales, and was of the usual quality; but the evaporation of water per lb. was rather above the average, the ordinary quantity being about $7\frac{1}{2}$ lbs. of water evaporated by 1 lb. of coal.

With the exception of the first-class carriages, all the others on the railway have a Break on every wheel, worked from the inside. The ordinary Passenger Trains consist of one first, one second, and two third-class carriages, with one break-van; and to these trains

Mr. Clark's continuous break is attached. This apparatus is worked by a chain, which tightens the breaks on every one of the wheels simultaneously. The breaks are taken off by heavy counterbalance weights, resting longitudinally over the chain in the centre of the carriage, between the front and end wheels. This apparatus is sufficiently powerful to lock every wheel, and has worked satisfactorily; for during two years there has not been a single fracture of the chain, nor of any of the working parts. It however requires careful management, and must be applied gradually, before the train has acquired serious momentum. The friction rollers must be kept revolving, otherwise the break-van wheels wear flat places or segments in the rollers, by which their use is completely destroyed. The continuous chain is also jerked, and an undue strain thrown upon it, and upon the carriage couplings, depending in intensity upon the concavity of the segment worn on the friction rollers, and upon the tension of the chain at the time. There has been much difficulty in getting men to work this break satisfactorily; and great difference has been found in the length of time a set of friction rollers would last, depending altogether upon the care with which they are applied. One Guard has worked a set of friction rollers for fully nine months without wearing them unevenly; while several other Guards have destroyed a set in one week, and in some instances in a single trip. To prevent the wearing of these cast-iron rollers, a wrought-iron strap, or tyre, about $\frac{3}{4}$ inch thick, has been placed on their circumference, and this has been found to decrease the wear and to answer well. In future it is proposed to make these tyres of $1\frac{1}{4}$ inch Bessemer steel. The break-van of every passenger train is now provided with sand-boxes leading to the rails, as formerly the dew on the rails wetted the wheels of the break-van, and prevented the friction rollers of the apparatus from revolving; whereas, as soon as sand was applied, the wheels became dry, and the friction rollers acted efficiently. The cost in London of the continuous break for four carriages and the van was £85 per set, to which must be added freight, insurance, &c., so that the cost in place in Mauritius may be taken at £91 per set.

Every train of four or five carriages has two guards, one to work the continuous break, the other to use the separate break if necessary, attached to the end carriage, or that which was not connected with the continuous break. In general, one additional breaksman is sent for every two carriages, beyond the four which are worked by the continuous chain. During the year 1867, the 7·30 A.M. up train from Mahebourg was much overcrowded, and frequently descended the inclines with eight or nine carriages attached; but, for the sake of giving more accommodation, and greater safety, another train has now been added, so that the ordinary trains at present vary from four to six carriages.

The heaviest passenger train from Mahebourg to Port Louis consisted of fourteen carriages and two break-vans, and conveyed five hundred and thirteen troops. This was on the 14th of November, 1868, and it was kept perfectly under control, when descending the inclines, by the continuous break on four carriages, and by five additional breaksmen, the speed from Curepipe to Port Louis being steadily maintained at 20 miles per hour.

Engines attached to trains have occasionally got off the line at the points, without doing any damage, through the carelessness of the pointsman; but, with this exception, since the opening of the line, in October, 1865, there has been no accident to any passenger or goods train, nor to any passenger. There are but four instances of passenger trains getting for a time beyond control:—First, one morning when the rails were wet, a train, consisting of four carriages and the break-van, descended from Curepipe to Phœnix, a distance of $3\frac{3}{4}$ miles, in five minutes, or at a speed of 45 miles per hour. This is the highest speed on record, and it occurred before the sand-boxes were put on the break-vans. Secondly, in a similar way, another train attained a speed of 32 miles per hour. Thirdly, a train overran the Petite Rivière Station for a considerable distance, chiefly from the want of sufficient care on the part of the engine-driver and guards. Lastly, a train once attained an excessive speed in descending from Curepipe to Cluny, through the dropping off of the nut of the eye-bolt which passes through the axle on which the continuous chain of the break apparatus is wound. The last is the only instance of any casualty having yet occurred with the gearing of the continuous break, and was moreover an accident not attributable to the system.

The speed in descending the inclines is limited theoretically to 18 miles per hour, practically it rarely exceeds 25 miles, and the breaks on the carriages are generally sufficient to control the train, without the necessity of applying the breaks on the engine. It was at first customary to use the engine break; but the iron tyres being then found to heat, so that they would soon become loose, the practice was discontinued, and the engine break is now only applied on emergencies. The present tyres of all the locomotives are manufactured from Bessemer or Krupp's steel.

The goods trains in descending the inclines, as a rule, consist of eight loaded wagons with the lighter locomotive, though ten have been occasionally taken, and as many as twenty empties. There have been instances in which fourteen loaded or twenty-four empty wagons have descended, but only on emergencies and under very favourable conditions. With the 48-ton locomotives the usual number of wagons in descending the inclines is from ten to twelve and sometimes fifteen loaded, or about twenty-four empty, and, in

these cases also, the breaks on the wagons control the trains, so that it is rarely necessary to apply the break of the engine.

The break power attached to the ordinary goods train is as follows:—First, two ordinary break-vans, or one break-van and one goods wagon fitted with the ordinary screw break. Secondly, every goods wagon has the usual break handle working two blocks on the wheels, and to the end of this handle a weight, averaging 35 lbs., is attached to every wagon, exerting (including the leverage) a pressure of 90 lbs. on the break blocks.

With every train, both passenger and goods, there are at least two guards. The head guard always works the principal break-van, and the under guard works either the second break-van or a screw break-wagon, one of which invariably accompanies each goods train. In addition, a man specially employed in tightening up the break blocks before descending on either side of Curepipe (or at any other station where it may be required) accompanies each train, both passenger and goods, and works the separate break of any additional carriage, or the second screw break-wagon if there should be two of them on the train in question. The head guard of each goods train always carries in his break-van twelve of the weights before mentioned, one to be attached to every wagon, and he takes them off as the wagons are left at the stations, in order that he may always have these weights with him. Ten spare weights are also invariably kept at Curepipe for use in case of emergency. To expedite the sugar traffic in the crop season, it is found necessary to carry three or four goods wagons with most of the passenger trains, the carriages of which are worked with the continuous break, but in this case, also, a weight is attached to every goods wagon, and the wagons are always placed in front of the carriages. The only instance on record of a goods train getting for a time beyond control occurred on 10th September, 1867. At Curepipe six loaded wagons were attached to a 37-ton engine. The breaks of all the wagons were then tightened up as usual, and the ordinary weights applied, but control of the train was lost between Curepipe and Phœnix, though, on reversing the engine, the train was stopped at the latter station. Two more loaded wagons were then added, and two more at Quatre Bornes Station, making ten wagons and the van, or 110 tons in all, and after leaving Rose Hill the speed again became excessive, and it was not until the engine had been reversed, that control of the train was re-obtained.

The idea of placing Safety Sidings at the foot of the steepest inclines, near Petite Rivière and Vacoa, into which could be turned trains which may get beyond control, has long been in contemplation, but the ground is by no means favourable for the purpose, and from the difficulty of working them efficiently, it

is feared that they may become a source of danger rather than of safety.

The electric telegraph, double needle system, is in use on this railway, and the trains are regularly signalled by it, but the telegraph lads have not yet had sufficient experience to be thoroughly reliable, and as notice to the switchman at these points must be sent by telegraph, it would require (although a simple system of signals could be adopted) a class of men very difficult to find in Mauritius.

The following rules are in force respecting vehicles which may get away from a station, or may break loose from a train, through the snapping of the couplings when ascending an incline.

First. That on a vehicle passing any station, the station-master is to telegraph immediately to the nearest station whither the vehicle is proceeding, stating whether there be human beings in the vehicle or not. In the latter case the wording for simplicity is as follows:—

Runaway { vehicle / or / train } upset.

Secondly. The station-master receiving this telegram is then to take immediate steps to throw the runaway off the line, by holding the nearest switch-points half open, or by the most available means.

Thirdly. If there be human life in the vehicle or train, or if the first station-master be not certain that there are no human beings in it, he is to telegraph to the nearest station as follows:—

Runaway { vehicle / or / train } life.

Fourthly. In this case the instructions to throw the vehicle or train off do not apply, but it is left to the station-master receiving the latter telegram, to act to the best of his judgment under existing circumstances, the first consideration being the preservation of human life.

The following Mauritian woods have been tried for break-blocks: Tatamaca, Calophane, Bois de Natte, and Bois de Pomme; of these Calophane has been found to answer the best. The average duration and cost of a set of break-blocks are as follows:—

	Duration.	Cost per Set.
Continuous break-blocks, four on each carriage.	21 days	9*s.*
Ordinary break-van, with four blocks	30 „	7*s.*
Ordinary goods wagon, with two blocks	26 „	3*s.* 6*d.*

All these break-blocks have three holes, each $\frac{3}{4}$ inch in diameter, drilled into the face, for a depth of about 3 inches, and these holes are filled with lead for the sake of increasing the grip upon the tyre, and of preventing the block from firing.

Owing to the short length of flat gradients upon which the stations are placed, the working of the sidings is rendered very inconvenient. So much is this the case at Beau Bassin, that trains are never allowed to pass there, from the fear of a collision if the train in descending from Rose Hill should get beyond control. Union Vale Station is also objectionable; and at all the stations great care has to be exercised with wagons left in the sidings. To prevent wagons from breaking loose, a heavy stop-block, say 12 inches square, passes over both rails of each goods siding previous to its junction with the main line, and these blocks are always kept strictly locked, except when the goods trains are actually passing through them. The rules especially provide, that no wagon is to be moved by hand, either on the main line, or on the through siding, nor beyond the limits of the stop-block, and that no wagon shall be uncoupled from the engine until brought to a dead stand within the stop-blocks. This latter rule, though somewhat relaxed in practice, has been fairly maintained, and only one instance of a wagon running away has yet occurred, and that through the carelessness of the station-master. In general a man is placed to shut the stop-block the moment the wagons have passed through it. As a principle, it is held essential to reduce the number of points on the main line to a minimum, and therefore the goods sidings always branch off from the through siding, and not from the main line itself.

It is impossible to give a fair statement of the traffic returns, on account of the exceptional circumstances under which the line is still working. For the first year's traffic the passenger receipts for 1866 may be taken as a fair commencement, and they are now steadily, though not rapidly, increasing, notwithstanding that the short sugar crops for four years, 1864—67, had seriously affected the prosperity of the colony, and have naturally diminished the amount of passengers, as well as of goods, which would otherwise have been carried. The unusual drought which since 1862 has prevailed in Mauritius has caused a most serious diminution of the sugar crop: the crop for the season 1862-63, which reached 158,161 tons, having fallen off to 108,237 tons in the season 1866-67. Owing also to the want of sufficient locomotives, and to the unusual wear of the iron tyres of the driving-wheels, which, through a defect in the manufacture, required to be two or three times 'turned up' after running on the average only 4,128 miles between each turning, the amount of goods conveyed during 1866 affords no criterion of the capabilities of the line. From February to July inclusive of the year 1867 the colony suffered from an epidemic fever, unparalleled in violence, the number of deaths having been 34,233 out of a population of 341,165, or more than 10 per cent. During the month of April, out of a population

of 75,000, the mortality of Port Louis averaged 207 per day, a rate sufficient to have exhausted the population of the town in one year, and, including the mortality in other districts, to have swept off the entire population of the colony in two years and nine months. Many whole families were carried off, leaving none remaining, business of every description was almost wholly suspended, and the revenue of the colony decreased by one half, the loss being about £1,000 per day.

Although it is but natural that the passenger traffic during the first six months of the year 1867 should have considerably decreased, as compared with the corresponding period of 1866, still the traffic for the whole of 1867 will compare favourably with that of 1866.

The following are the figures in each case:—

——	1866.	1867.	Increase.	Decrease.
Number of Passengers	519,524	430,052	..	89,472
	£	£	£	£
Passenger Receipts	31,979	30,225	..	1,754
Parcel Receipts	546	797	251	..
Telegraph Receipts	..	43	43	..
Miscellaneous Receipts	11	102	91	..
Suspense Traffic	173	..	..	173
	tons.	tons.	tons.	tons.
Goods, Number of Tons	18,047	31,998	13,941	..
	£	£	£	£
Goods Receipts	7,675	14,272	6,597	..
Total Revenue	40,384	45,439	5,055	..
Total Expenses	25,319	30,856	5,537	..
Profit for the Year	15,065	14,583	..	482

The passenger rates are as follows:—

First class	. 4*d.*	per mile.
Second ,,	. 2½*d.*	,,
Third ,,	. 1*d.*	,,

Return tickets for the first and second class being 50 per cent. more than the fare for a single journey.

The rates for goods vary according to the usual classification, but for sugar, provisions, and manure, which form fully three-fourths of the whole tonnage, the charges, including terminals, are as follows:—Sugar and provisions from Mahebourg to Port Louis, 35 miles, or *vice versâ*, 10*s.* per ton, equal to 3·42*d.* per ton per mile. Sugar and provisions from Rose Belle to Port Louis, 24 miles, or *vice versâ*, 9*s.* 2*d.* per ton, equal to 2·60*d.* per ton per mile. The rates for these articles from stations intermediate between Rose Belle and Port Louis are about 5½*d.* per ton per mile. The charge for manure from Port Louis to Mahebourg is 7*s.* 6*d.* per ton, equal to 2·60*d.* per ton per mile.

The short distance of this railway (single line) tells of course greatly against the receipts, and, from the severe character of the gradients, it has never been deemed prudent to run trains by night.

During the year 1866 the locomotive cost per engine mile run was unexceptionally high. The price of fuel then averaged 41*s.* 5*d.* per ton, or, including delivery and stacking, 44*s.* 5*d.* Again, the iron tyres of the side-tank engines wore so rapidly, and the number of locomotives for the work was so small, that a considerable additional expense was incurred beyond their fair repairs. These disadvantages have now been remedied, and the locomotive cost per engine mile run is at present as follows:—

	d.	*d.*
Cost of fuel per mile		10·90
„ oil, tallow, and waste		1·20
„ materials for repairs of engines	2·08	
„ „ „ carriages and wagons	1·84	
		3·92
Salaries of superintendent, drivers, firemen, and cleaners		6·19
„ mechanics repairing engines	2·57	
„ „ „ carriages and wagons	1·40	3·97
Total per mile run		26·18

The consumption of fuel per mile run is 49·7 lbs.

As these expenses are still double the cost at home, it is necessary to make a few remarks respecting the value of the skilled labour and the supplies obtained from England. The engine-drivers, carriage foreman, and platelayers were all engaged in England to serve in Mauritius for three years certain, it being optional with the Government to extend the agreement to five years, on giving notice to that effect six months prior to the expiration of the former period. The salary of the engine-drivers is for the first year £192, for the second year £216, and for the third year £240. Sunday work is paid for in addition at the ordinary rate, and the drivers have also the use of free quarters. The salary of the carriage foreman was £300 per annum, but this office is now filled satisfactorily by a Mauritian at about £150 per annum. The platelayers receive £150 per annum, with a bonus of £25 per annum on receiving a certificate of good conduct; and they also enjoy free quarters, though this advantage is neither in their agreements nor in those of the drivers. The Government provide free passage for all these men from England to Mauritius and back (except in case of misconduct), the expenses thus incurred being about £130 per man. As yet no attempt has been made to train engine-drivers in Mauritius, it being difficult to find men having sufficient nerve and intelligence, although it is hoped that some of the lads now training in the shops may eventually become drivers.

All other skilled labour is found in Mauritius. The Creole carpenters, masons, blacksmiths, and fitters are fair workmen, though slow and not over industrious. Comparing their wages and amount of work done with the value of similar labour in England, the cost in Mauritius is from 10 to 15 per cent. more than at home.

The maintenance of the permanent way is under the charge of English platelayers, whose districts average 12 miles each, and who superintend the Coolie labour. Every day, wet or dry, Sunday inclusive, each district is minutely inspected on foot by a reliable Indian, who carries a keying hammer; and this man is frequently accompanied by another Indian carrying a spanner. In addition to the ordinary platelayers' rules, special instructions have been given respecting repairs on the Midland line. After a little practice the Indians work well at packing the sleepers, and keep the road in very good condition. The number of Coolies required averages four per mile, and their usual wages are £10 per annum, plus rations, the ordinary value of which is £5. 10*s.* per annum. The cost of all salaries and labour employed in maintaining the road, but without any renewals worth mentioning, none of which have as yet been required, has been as follows:—

	Per Mile per Annum.		
	£.	*s.*	*d.*
Salaries of Engineer, Inspector, and Office expenses .	20	0	0
Wages of platelayer	14	12	0
Coolies, four at £15. 10*s.* each	62	0	0
Tools, about	3	8	0
	£100	0	0

During the years 1864 and 1865 contracts were made in England for the supply of fully 6,000 tons of Newcastle and Welsh coal, to be delivered in Mauritius at prices ranging from 34*s.* to 49*s.* 10*d.* per ton, and in consequence of freight being then unusually high this coal averaged 41*s.* 5*d.* per ton. Latterly Australian coal, from Newcastle, Wallsend, and Warattah mines, Sydney, has been found very satisfactory, and equal to any English coal imported; so much so that it will be chiefly used in future. The cost of this coal, delivered in Port Louis harbour, is usually 32*s.* to 40*s.* per ton. The cocoa-nut oil manufactured in the colony, and used for the locomotives, and for all machinery, answers well. The ordinary price is 3*s.* 4*d.* per gallon. Tallow is obtained from Australia at 7*d.* per lb., and carriage grease is made by the Department at a cost of about 70*s.* per cwt. With these exceptions the usual stores are chiefly obtained from England, the price of ironmongery and of most articles being fully double their cost at home, and often more. The cost of freight,

packing, and insurance on articles received from England, adds nearly 14 per cent. to their original value when delivered in the colony.

Considering, therefore, the high price paid for skilled labour and for fuel, the agricultural character of the district through which the railway passes, the severity of the gradients, the want of anything that can be called a town save at Port Louis, the lack of minerals or manufactures to transport, the peculiar nature of the sugar traffic—requiring a large amount of rolling stock for three months in the year, whereas for the remaining nine months less than half that quantity would suffice—under all these unusual circumstances it is not surprising that the working expenses of the Midland line should, in 1866, have been 62½ per cent. of the receipts, or 5*s.* 5*d.* per train mile.

Fortunately some of these exceptional circumstances have now ceased to exist. The arrival of the 48-ton engines has enabled a larger amount of sugar to be carried; and when the goods traffic becomes further developed, a considerable decrease in the per-centage of working expenses to the receipts will naturally ensue, accompanied also, it is hoped, by a reduction in the cost per train mile.

It may be, of course, sometimes impossible to construct a railway with easier gradients than those on the Midland line; but the difficulty of working these inclines in wet weather has been so great, the load hauled so small, and the speed so low, that the Author thinks the severity of any gradient for a long rise should never exceed 1 in 40; and that it will always be preferable (under the ordinary system of tractive power) to incur, within reasonable limits, any additional expense that may be requisite to bring the inclination within this ratio. It is also suggested that in laying out such inclines, whatever may be the ruling gradient (provided it be not entirely exceptional, and where additional power can be applied) that this gradient be then followed throughout the line, as far as the features of the country will permit; pieces of level being introduced between the different inclinations, as, on descending, these level portions are found of the greatest value in controlling the train. The Author believes it to be safer to work steeper gradients, provided there be pieces of level between the different inclinations, than to work a uniform gradient, extending both over the former inclines, and over the level portions, the ratio of all these inclinations being of course within reasonable limits, or say not steeper than 1 in 40.

The Appendix contains a summary of the gradients and curves (Nos. 1 and 2), the details of the locomotive engines (No. 3), and schedule of the rolling stock (No. 4). Attached to the original Paper, which may be consulted at the Institution, will be found

a copy of the "Working Time-table, 1st August, 1867;" return of the imports and exports in Mauritius from 1860 to 1866 inclusive; statement, showing the population, revenue, and expenditure of the island, and the immigration returns between the same dates; a memorandum of the steam machinery, and of the value of labour and materials in the island; and meteorological observations taken at Port Louis in the year 1865. These have been chiefly extracted from Blue Books.

The communication is also accompanied by Maps of Mauritius and of Port Louis, showing both lines of railway, and by a section of the Midland line, from which Plate 12 has been compiled.

APPENDICES.

No. 1.

MIDLAND LINE.

Summary of Gradients Rising from Port Louis to Mahebourg.

Ratio.	Length in Feet.	Rise in Feet.
1 in 27	13,526	499·27
1 in 30	9,526	317·85
1 in 34	2,100	61·76
From $\frac{1}{36}$ to $\frac{1}{40}$	4,800	128·23
1 in 40	11,460	286·50
$\frac{1}{40}$ to $\frac{1}{50}$	9,050	195·25
$\frac{1}{50}$ to $\frac{1}{60}$	6,900	123·37
	57,362	1622·23
$\frac{1}{60}$ to $\frac{1}{70}$	2,172	32·50
$\frac{1}{70}$ to $\frac{1}{80}$	4,700	62·69
$\frac{1}{80}$ to $\frac{1}{90}$	3,220	37·82
$\frac{1}{90}$ to $\frac{1}{100}$	350	3·89
1 in 100	1,000	10·00
$\frac{1}{100}$ to $\frac{1}{200}$	7,466	58·56
Over $\frac{1}{200}$	7,180	19·40
Total feet rising	83,450	1847·09

Summary of Gradients Falling from Port Louis to Mahebourg.

Ratio.	Length in Feet.	Fall in Feet.
1 in 30	7,510	250·29
1 in 31	5,340	170·24
1 in 32	5,900	184·37
1 in 34	3,514	102·64
1 in 35	1,400	40·00
1 in 36	3,800	105·32
$\frac{1}{36}$ to $\frac{1}{40}$	3,300	86·20
1 in 40	8,967	224·17
$\frac{1}{40}$ to $\frac{1}{50}$	11,974	276·86
$\frac{1}{50}$ to $\frac{1}{60}$	6,100	116·43
	57,805	1556·52
$\frac{1}{60}$ to $\frac{1}{70}$	11,400	183·93
$\frac{1}{80}$ to $\frac{1}{90}$	2,050	25·35
1 in 100	2,900	29·00
$\frac{1}{100}$ to $\frac{1}{200}$	4,400	33·04
Over $\frac{1}{200}$	6,864	19·75
Total feet falling	85,419	1847·59

Total level 17,033 feet.

No. 2.

MIDLAND LINE.

Summary of Curves.

Radius in Feet.	Length of Curve in Feet.	Feet.
950	1,200	
1,300	1,100	
1,400	3,330	
1,500	1,600	
1,600	3,690	
1,750	750	
1,800	5,260	
1,900	2,485	
1,930	1,000	
1,950	750	
Total length under 2,000 feet radius .		21,165
2,000	20,050	
2,200	600	
2,250	390	
2,300	400	
2,400	7,500	
2,500	550	
2,700	830	
2,800	780	
2,930	2,060	
3,000	3,200	
3,070	600	
3,200	8,010	
3,260	1,740	
3,400	700	
3,600	2,300	
Total between 2,000 and 4,000 feet .		49,710
4,000	11,890	
4,265	2,000	
4,700	250	
5,000	5,730	
5,600	600	
6,000	5,090	
Total above 4,000 feet .		25,560
Straight . .	.. ..	89,467
Total length .	.. ..	185,902

No. 3.

MAURITIUS RAILWAYS.

Principal Dimensions of Tank Engines on Midland Line.

Class of Engine.	Number of each Class.	Wheels.		Cylinders.		Tubes.			Heating surface, Square Feet.			Grate Area, square feet.	Blast-pipe.		Wheel base.			Capacity of Tank, gallons.	Weight in working order in Tons and Cwts.				Ratios.			Capacity of Cylinder in cube feet per mile.	Heating surface to Cylinder, capacity per mile. Square feet H. S. to cube feet Cylinder capacity.	Weight on each Wheel in per centages.			Weight to heating surface, Cwts. per Square Foot.	Tractive force.		Weight in Cwts. to cube foot of Cylinder capacity per mile.
		Diameter.	Number (all coupled).	Diameter.	Length of Stroke.	Number.	Length.	Diameter (outside).	Tubes.	Firebox.	Total.		Diameter (inches).	Area (square inches).	Front to Middle.	Middle to Trailing.	Total.		Leading.	Driving.	Trailing.	Total.	Tubes to Firebox.	Heating surface to Grate.	Fire-grate to Blast-pipe.			Leading.	Driving.	Trailing.		At 60 lbs. mean effective pressure.	To adhesive Weight.	
		′ ″		in.	in.		′ ″	in.				′ ″	in.		′ ″	′ ″	′ ″														lbs.		
Side Tanks	7	3·6	6	16	22	166	10·6	2	919	82½	1,001	15·8	4½	15·9	7·0	8·0	15·0	1,200	11,1	12,14	13,3	36,18	11·13	63·3	143	4,917	0·203	30	34·4	35·6	0·737	8,046	·097	0·1501
Saddle Tanks	6	4·0	8	18	24	159	13·6	2	1,122	90·7	1,213	18·0	4¾	17·7	To 2nd leading. 4·3 / 6·1½	5 1½	15·6	1,500	12,3 / 11,17	12,11	11,2	47,16	12·37	67·4	146	5,940	0 204	25·4 / 24·8	26·5	23·3	0·788	9,720	·090	0·1609

(Signed) Walter H. Scott,
Locomotive Superintendent.

No. 4.

MAURITIUS RAILWAYS.

Schedule of Rolling Stock.

			Total.
North Line.			
Passenger Locomotives	4		
Goods ditto	4		
		8	
Midland Line.			
37 ton ditto	7		
48 ton ditto	6		
		13	
			21
Carriages.			
First class	12		
Composite	11		
Second class	11		
Third ditto	60		
			94
Horse boxes			6
Carriage trucks			4
Break Vans.			
Passenger trains	6		
Goods ditto	14		
			20
Goods Wagons.			
Covered	62		
High sided	110		
Low sided	16		
Ditto for timber	8		
		196	
Ballast wagons		28	
Coal ditto		6	
Total Wagons			230

[Mr. Hemans

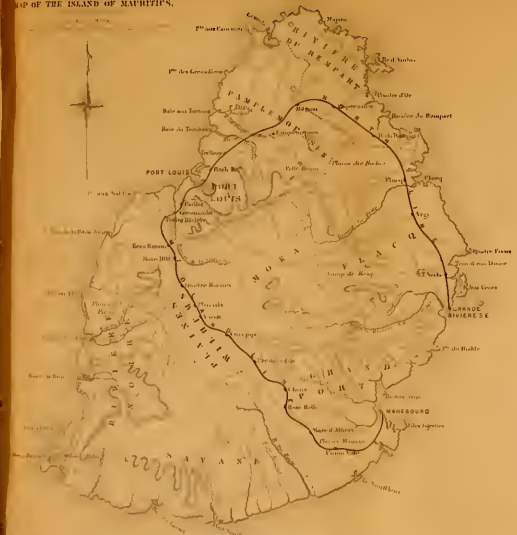
Mr. Hemans thought the Author had enunciated a principle which no engineer of the present day would be inclined to accept, viz., that no railway should be made with long continuous inclines steeper than 1 in 40. For his own part, rather than consent to such a limit, he would be disposed to look for improvements in the locomotives. It appeared strange that the class of engine described in the Paper should have been selected for working these inclines. An engine weighing 48 tons, on eight wheels all coupled, without much arrangement for moving round sharp curves, and with a wheel base of 15 feet, or about the length of a rail, must be dangerous and unsteady when applied to that kind of work; and the effect of such an engine breaking loose, and running down an incline at the rate of 45 miles an hour, must be ruinous to the permanent way. Engines had been so improved that, with mechanical assistance, as, for instance, on the Mont Cenis railway, they could ascend inclines of 1 in 13 without any extraordinary weight on the driving wheels. In his opinion more attention should be paid to distribute the weight of the locomotive so as to obtain sufficient adhesion upon such inclines as 1 in 27 or 1 in 30, without placing such heavy weights upon any pair of wheels.

With regard to the suggestion of catch sidings at the foot of inclines, he apprehended the danger would be thereby increased. The newspapers recently contained an account of an accident on the Bhore Ghaut incline of the Great Indian Peninsula railway, where the engine and the whole of the train ran over the end of the reversing station. This he feared might be the case at the catch sidings, unless the contour of the ground was such as to enable them to be laid out so as to bring the counteracting check of a reverse gradient to bear upon the trains; otherwise there must be enormous and costly spring buffers at the end of the sidings, to resist the impetus of the train. He thought, on the whole, it was safer to let an engine run away down a long incline, with a chance of controlling it at places where the rails were less slippery, or on any intervening levels, rather than adopt catch sidings which he believed would not lead to increased safety.

Mr. J. A. Longridge said he was responsible for the gradients adopted on this line of railway, inasmuch as long before he had any idea of being connected with its construction, he was commissioned to investigate and report whether railway communication could be made commercially successful in the Mauritius, and if so, to select the lines most deserving of attention. With the North line, which passed through the greatest sugar-producing district, there was not much difficulty: it was merely a question of the cheapest line. But with the Midland line it was altogether different; for to reach the south-east side of the island, a summit of 1,800 feet had to be surmounted, the distance in a direct line being

THE MAURITIUS RAILWAYS.

MAP OF THE ISLAND OF MAURITIUS.


PORT LOUIS
PORT LOUIS
MOKA
PAMPLEMOUSSES
GRANDE RIVIERE S.E.
BLACK RIVER
MAHEBOURG
SAVANNE
Quatre Bornes
Curepipe
Rose Hill
Beau Bassin
Plaine Wilhems
Grand River South East
Grand River North West
Tamarin Bay
Flacq
Port Louis Harbour
Mahebourg Bay
Pointe aux Sables
Pointe d'Esny
Pointe Jerome
Pointe Canon
Pointe Bernica
Pointe Lascars
Pointe Jacotet
Pointe Diamant
Pointe Rouge
Pointe Lafleur
Pointe Lafouche
Pointe Lafouche
Pointe Lafouche

only about 13 miles. He saw at once, from the statistics he obtained, that it was of the utmost importance to the island that the Midland line should be made, more so even than the Northern line, because it was evident that the south-eastern district would become the great future sugar-producing portion of the Mauritius. In that opinion he had been confirmed, because, from the cutting down of the forests in the centre of the island, and the consequent diminution in the quantity of water feeding the northern part, the sugar produce of that district had decreased in a remarkable degree. Some of the estates which were the finest when he first visited the island were now scarcely worth cultivating; on the other hand, estates on the south-east side of the island had become more valuable. The means of transit of the produce to the ports of shipment became, therefore, of the utmost importance; hitherto it had been carried on by small schooners with great loss and delay. He therefore recommended that the Midland line should be carried out with as little delay as possible. The first question of course that had to be decided was the extreme gradient which might be adopted; and in that he was guided a good deal by past experience. There were lines with large traffic, with gradients of 1 in 27, and he accordingly came to the conclusion, that if that gradient could be obtained he would adopt it. When the Author of the Paper laid down the principle that no gradient should be steeper than 1 in 40, it was all very well if the country was suited for that gradient: if not, such a gradient must be adopted as the country would admit of. The result of a subsequent investigation and survey, in which he was accompanied by Mr. Walmsley Stanley (M. Inst. C.E.), was to prove that the line selected in the first instance was the best. As to a gradient of 1 in 40, in that country it was simply impossible. With his subsequent experience, if he had this railway to lay out again, instead of 1 in 27 he would have recommended 1 in 12, to be worked on the centre rail system, which he was satisfied could be made both mechanically and commercially successful. It had not been fairly tested as yet on the Mont Cenis line, because disasters of all kinds had been encountered, owing to the bad quality of the engines, both in workmanship and materials. But in spite of that, he thought the working expenses of that line would compare favourably with those of the Mauritius line, either per train mile, or per-centage of receipts. Within the last month he had been able to arrive pretty accurately at the cost per train mile of the Mont Cenis railway; and with all the disasters, the short mileage, and the heavy establishment charges, it came only to 5*s*. 9*d*. per train mile.

Mr. Gregory, President, inquired what was the net load carried at that cost.

Mr. Longridge said, exclusive of the engine and carriages, the

net load in goods averaged from 20 tons to 24 tons. That was not, however, a fair criterion, because the weight of the carriages must bear a fixed proportion, whether on a level or a gradient of 1 in 12. The only proof was the per-centage of working cost upon the receipts; and in the case of the Mont Cenis railway, at the present time the working expenses were 69 per cent. of the receipts. He was far from being satisfied with that; and he believed in a short time that the cost would be reduced to 4*s*. 6*d*. per train mile, and with an increased traffic, which progressed every day, that the working expenses would be brought down from 69 to 50 per cent. This was of course only an opinion, as it had not yet been done. He was surprised that the working expenses of the Mauritius line had reached so high a figure. He did not know what the actual working expenses had been for 1867—68; but in the estimates presented to the Government for 1869, he was sorry to find the working expenses put down at something like 70 per cent. of the receipts. This he could not understand, as coals cost more on the Mont Cenis line, and the rate of wages was quite as high as in the Mauritius. It was an exceedingly unsatisfactory position for this railway, which he once believed would have been a great benefit to the colony. Mr. Longridge was not aware what reasons had led to the adoption of the heavy eight-wheel coupled-engines. He did not think it a suitable class of engine for the traffic. He would have preferred two four-wheel engines,—one to be placed in front, and the other in the rear of the train. He believed that plan would have answered better, as a high speed was not required.

Mr. Bramwell wished to know what was the average gradient of the Mont Cenis line to which the train mileage given was applicable. He found the average gradient on the Mauritius line was 1 in 50 at one end and 1 in 43 at the other. He also asked what on the Mont Cenis line was the weight of the engine, compared with that of the goods and the wagons which the engine drew?

Mr. Longridge replied, that the greater portion of the Mont Cenis line, on the Italian side, was 1 in 12 and 1 in 13. On the Susa side the average gradient was 1 in 15. The engines weighed, when supplied with coke and water, about 19 tons each; and when the rails were in a favourable condition, each engine would take a train of 30 tons net load, wagons and goods included, or, including the engine, of 49 tons. At some seasons of the year the weight of the trains was limited to 18 tons or 20 tons. These figures must not be taken as of much importance, for the principle on the Mont Cenis line was that of getting the adhesion of the central rail. It was calculated to put a pressure of 30 tons on the central rail; but owing to the bad quality of the materials of the engines, that pressure was obliged to be reduced considerably, and he did not think it was more than 12 tons or 14 tons.

Consequently the loads now carried were less than would be the case if the engines were of a better description. It was not because there was not steam or power enough, but because if the necessary pressure were applied upon the rail, the engine broke. The figures he had given represented what was done under the present difficulties, not the results that would ultimately be accomplished by the central rail system. The gauge of the Mont Cenis line was 3 feet 8 inches.

Mr. Mitchell remarked that on ordinary railways, however well constructed, there were irregularities in the surface of the rails, which were aggravated by wet weather, or bad ballast. These created oscillations in the train in proportion to the extent of the irregularities. On the Mont Cenis railway it appeared to him that the centre rail must be inflexible, the horizontal wheels biting in proportion to the steepness of the gradient. He would ask whether the oscillations of the train, caused by the irregularities of the side rails, did not tend to disturb the rigidity which was necessary for the proper working of the centre rail.

Mr. Longridge replied, that springs were applied both to the central wheels and the vertical wheels, and any inequality in the road, either in the central or the ordinary rails, was compensated at once by the springs. One difficulty at first experienced was from the fact of the compression spindle, which brought the central wheels together, being rigidly connected with the frame of the engine. That threw a great strain upon it, and it broke. By giving a little play to the spindle, this was overcome. When the engine oscillated sideways as well as vertically, it was all taken up by the springs.

Mr. Huntington said, he was acquainted with every part of Mauritius, and could state that, in his opinion, the choice of gradients on the Midland line could not have been better: for in the centre of the island there was a high ridge which had to be surmounted, and it could not be avoided by going either to the right or to the left. The railway might have been constructed at a higher elevation, but he doubted if it could have been carried at a lower level; at least, not without a considerable detour, and by abandoning the chief course of the existing traffic, habitations, and cultivation, as well as the important neighbouring district of Savanne: as it was, it took a mean direction. With regard to the present position of this railway, there were several circumstances to be considered. It might now be said to be under a considerable amount of trial and suffering. It was not paying, and this was due to a variety of causes. The fares were high as compared with the European standard, fourpence per mile being the charge for first-class passengers over a distance of 24 miles, from Port Louis to Rose Belle. Of course, in regulating the

charges, the cost of the line had to be taken into consideration. For nearly the whole length it was a single line, and £21,000 per mile for a single line looked a large price. The works were heavy, and the cost, under exceptional circumstances, was undoubtedly much more than had been anticipated. After leaving Curepipe to descend to Petite Rivière, there were very steep gradients, combined in several cases with sharp curves, particularly between Phœnix and Beau Bassin, and also near Port Louis. He alluded to this, because he thought the attention of engineers should be directed to the construction of locomotives and carriages of such a nature as to be more suited to the circumstances of railways like those in Mauritius than the rigid structures at present in use. The management, guards, and engine-drivers, were entitled to great praise, as the traffic had hitherto been conducted without accidents. He should also mention that at the Coromandel Station there was a heavy viaduct, the construction of which formed a large item in the cost of the line. That viaduct was, he believed, 110 feet in height, and in March, 1868, during a hurricane, the iron superstructure was blown off the piers, and carried into the river. It had since been temporarily restored by timber lattice-work, and the question had arisen whether in such a position, in a deep ravine, exposed to fearful hurricanes, the lattice system was not best suited for such a structure. He hoped the prospects of the railway would improve: it had had to contend with adverse circumstances of bad crops, and the terrible fever in 1867, so that he feared it might be some time before it would become a paying concern.

Mr. Gregory, President, observed that the attention of engineers had been much directed to the subject just referred to; and that progress had been made—notably by Mr. W. B. Adams—in adapting engines and carriages to the traversing of severe curves.

Mr. W. B. Adams supposed it would be generally admitted, that where there were sharp curves the vehicles which had to traverse them should be of a suitable construction for the purpose. To reduce the wheel and flange friction to a minimum, the wheels must move freely beneath the frame, to the right and to the left, to suit the diameters of the cones to the varying lengths of the two rails on curves, and pointing their axles truly to the centres of the curves. Thus all flange friction would be avoided. For want of this arrangement, trains were limited in length to what could be forced into the shunts, probably not two-thirds of the full load on the straight line, and the couplings were severely strained. The purpose of breaks was to absorb the momentum of a train, and bring it to a stand, either when at speed on a straight line, or against the force of gravitation on an incline. The operation of the breaks was by friction against the wheel tyres, and on the

efficiency of this friction depended the result. The ordinary mode of obtaining friction was by pressing a block of soft wood against the wheel tyre, which was rapidly destroyed, and more rapidly when the fulcrum was unsteady, as in the ordinary mode of suspending the blocks from the body of the vehicle. To obtain the maximum of friction the block should be of metal, copper-lined, and covering the whole breadth of the tyre and flange with a wedging action. The fulcrum should be from the axle-box or axle direct, ensuring true action on the periphery. The breaks should be self-acting by the power of gravitation—a constant force—the normal condition being constant pressure till taken off; the direct opposite of the ordinary system, requiring manual or other force to apply the breaks, and therefore subject to neglect. The proper mechanical appliance was a long gravitation lever with the blocks at the end, acting like a steelyard beam, with a large weight at the short end pressing on the wheels, and a small weight at the long end, by which it could be lifted when it was desired to take off the pressure. If the gravitation lever multiplied twelve times, 84 lbs. at the lifting end would put a pressure of 9 cwt. on a pair of wheels, and as two levers might be used to each vehicle, a retarding force of 18 cwt. might be obtained—less the slip between the block and the wheel, which would be reduced to a minimum by the mode of application. The gravitation lever was recognized in coal and other wagons, but not properly as a travelling break. It was simply a clog applied when the wagon was at rest, in which case the suspension from the moving body did not affect it as a fulcrum. It might be taken as an axiom, that in whatever space a loaded wagon at a given speed, or on a given incline, could be stopped, with a given amount of retarding force, a whole train might be brought up in the same space with a proportionate amount of power.

Having shown how a pair of gravitation levers might be applied with a pressure of 18 cwt., or more, if required on the four wheels of a wagon, the question was how to manipulate this in a long train when running. The long end of the lever should be provided with a running sheave, through which a chain could be passed, one end to be attached to the wagon body and the other to the lifting power. In this way the weight of 84 lbs. at the lever end would be reduced to 42 lbs.; and by an intermediate snatch-block it could be again reduced to 21 lbs. A hempen cord about $\frac{1}{2}$ inch in diameter would be passed from one end of the train to the other, from the engine to the guard's van. This cord would descend in bights, or loops, to the snatch-block between every pair of wagons; the ends of the cord being affixed to winches on the engine and on the van. Thus the whole of the levers could be lifted by winding up the cord from either end. And as

the cords and lifting chains could diverge from the vertical towards a horizontal line, there would be abundant play in the chains and couplings. Supposing a gravitation pressure of 18 cwt. per wagon, the lifting force required at the winch would be 42 lbs., reduced to 14 lbs., if the winch multiplied three times. Thus, in a train of forty wagons, the lifting force required would only be 560 lbs., and this equally divided between the guard and the stoker would be 280 lbs. each. An objection would doubtless be made as to complication in making up and dividing trains. To meet this, every wagon should be provided with a hand-lever at each end, which, by the application of a force of 42 lbs., would put the breaks of one wagon, or any number of wagons, out of use when needed; and the lifting-cord could also be divided into lengths by couplings. The whole of the workmanship might be of the commonest kind, needing no accurate fitting. The 'modus operandi' would be as follows: When the engine-driver was about to start, the stoker would wind up his winch and lift the whole of the breaks. When about to stop, the stoker would draw out a catch, and as the barrel revolved, the whole of the breaks would press in succession on the wheels, and the stoker could again lift them at pleasure in succession.

There were two objections to the common system of breaks; they were inefficient in power, and they were slow in operation, and this was a frequent cause of accidents. The tender-break must be on before the steam could be reversed, and the guards must be signaled at a distance. There was no apparent reason why a pair of small steam-cylinders should not be applied, to draw up wedge-breaks between the coupled driving-wheels of the engine, whether four or six, and thus retard the whole, allowing the driver instantly to reverse the steam, while at the same moment the stoker was releasing the whole of the train breaks and applying the tender or tank breaks, thus putting every wheel under powerful friction. In numerous cases the train could thus be stopped and collision avoided. Another frequent cause of accident was the breaking of a coupling, especially on steep inclines. The train perhaps separated into two parts, the engine proceeding with one half and the other half advancing slowly until the motion was reversed by gravitation. If it acquired speed backwards before the guard could apply the breaks, the application became difficult and frequently impracticable; but with the self-acting breaks just described, the severance of a coupling ensured the severance of the lifting-cords, putting all the breaks at once in action, not only on the hind portion of the train, but on that attached to the engine, thus calling the driver's attention by decreasing speed. It would act as a signal to the driver, and with very little loss of time he could recover the severed portion of the train.

Separate tenders to engines had their advocates, as a useful medium for breaks; but the separate tender had many disadvantages. With the tender and engine on one frame, a balance could be obtained which would permit the use of very large outside cylinders, enabling crank axles to be dispensed with, and perfect steadiness to be ensured in running. An engine could be arranged with six or eight driving wheels and four or six radial trailing wheels, cylinders 20 inches in diameter, and tank capacity for 2,600 gallons of water, the total wheel base of which need not exceed 30 feet, yet adapted to run round curves of 3 chains' radius without flange friction. All the wheels might have breaks, and the frame could be separated when required for lifting. Radial buffers and radiating traction might be adapted to this engine to suit similar trains on curves. The system of self-acting wagon or carriage breaks could be applied either to radial or rigid vehicles. The tank break might be brought into action by chains and a small capstan under the foot-plate, falling off by gravity; the breaks, being suspended from the axle-boxes, would follow the wheels in their radial movement.

With the constant increase of traffic, the number of trains could only be lessened by increasing their size and weight, and to do this their resistance must be reduced to a minimum, and ample self-acting break-power must be obtained. Some practical men alleged that, upon the whole, it was more profitable to take risks than to expend money in preventing them. But it would be easy to demonstrate that, when hard work had to be done, the most perfect machine was also the best paying one.

Mr. Adams submitted that this system of self-acting breaks supplied an element of safety of the greatest importance, especially in the case of steep inclines and of suburban lines where quick stopping and starting at frequent stations were needed. It might be alleged that lines of railway made quite straight, without curves, were best, and that rigid vehicles might be used on them with fixed parallel axles, and without flange friction. This was a fallacy, as there was no such thing as a straight line of rails in the sense of a pair of lathe-beds. Each pair of wheels, as constructed, formed a double cone, which theoretically compensated for differing lengths of rail pathway, by shifting the bearing on to different diameters. But to do this the wheels must have free lateral movement instead of being confined by the frames, and this movement to be true should be radial, with the axles pointing truly to the centres of the curves. Any one who watched rails when in use knew that the tread surface on which the wheels ran was not a straight line, but a series of small curves, running irregularly to the inner and the outer sides of the rails, and consequently, with the wheels working on varying diameters, inducing

a sledging movement involving great friction, as evidenced by the wearing of tyres and rails. There was no remedy for this but giving the wheels free lateral play, and it had been found, in practice, that allowing the axle-boxes free end movement in the horn-plates was one mode, though not a very mechanical one, of alleviating the difficulty to a small extent.

In all countries there were natural gradients, varying according to the geological structure, and indicated by the course of streams where any existed; and these gradients mostly followed curved courses. Upon the whole it would be found, that the cost of the curved line, following the natural gradients, would be considerably less than that of the straight lines, and the working, unless in extreme cases, not more costly. It must not be forgotten that on so-called straight lines, points and crossings, shunting places, and approaches to stations and other 'turns out,' were practically all sharp curves. Of course the same speeds could not be attempted on curves as on straight lines; but there were many cases where great speeds were not required, and it was perfectly practicable to work a continuous series of S curves as sharp as 50-feet radius.

Mr. Harrison, Vice-President, thought this Paper involved many points of novelty, particularly when taken in conjunction with recent experience in the working of the Mont Cenis line, and the whole question was one that deserved full and deliberate discussion. He did not like the idea of an engine with eight wheels all coupled, particularly for traversing curves of small radii; as, when of ordinary construction, he did not believe such an engine was at all applicable for the purpose. He knew from experience what took place with engines with six wheels coupled on sharp curves. After being turned out of the shop and first put upon the line, the engine most probably would not go round sharp curves at all; and the only thing then to be done was to ease all the axle-boxes, and give so much play, that the engine would accommodate itself to the curve. But when an engine had eight wheels all coupled, he confessed he did not see his way to such an engine working satisfactorily.

Then came the question,—having to surmount steep gradients, what plan should be adopted? He had not visited the Mont Cenis railway, or seen the engines at work; but he did not think the short experience of the working of that line could be taken as conclusive of the final and practical success of that class of engine, if applied generally on a large scale to steep gradients. He therefore withheld his assent at present to that system being admitted to be perfectly successful; but at the same time he should be exceedingly glad to find, that the opinion he had formed—not having seen it in operation—turned out to be wrong.

Mr. Adams had stated that he could make an engine which would pass round curves of 3 chains' radius. He knew that gentleman's radial motion had been successfully applied to engines and carriages, and he had no doubt Mr. Adams was going in the right direction in designing stock for traversing sharp curves; but still he thought it would be much better, if it were possible, to avoid sharp curves, and thus remove the necessity for adopting these means of working. It was only when the curves were exceedingly sharp that it was necessary to resort to these expedients. There was no stronger argument against very sharp curves than the comparative wear of crank-axles on curves and on straight lines; and he could state from experience, that a crank-axle in an engine working on straight lines would last at least six times longer than the crank-axle of an engine working over exceedingly sharp curves.

As to Mr. Longridge's statement, that if he had to lay out the Mauritius line again he would not adopt the average gradient of 1 in 30, which he had recommended on that line, but, instead, a gradient of 1 in 12,—Mr. Harrison did not know the particular features of the country, and it was possible that by having a much steeper gradient the line might have been constructed at less cost. Still Mr. Harrison would hardly under any circumstances adopt a gradient of 1 in 12, where it was practicable to obtain a gradient of 1 in 30, as he did not think that, either as a question of economy or of facility in working, such a thing was desirable.

With regard to the commercial question, it appeared that the total cost of the Mauritius railways, although only for a single line, had been nearly £22,000 per mile, and that the working expenses amounted to 62 per cent. That would require, as nearly as possible, £3,000 per mile per annum, or £57 per mile per week, of receipts to pay 5 per cent. upon the cost. At the same time the train mileage receipts were 8*s.* 7¾*d.*, which was above the average mileage receipts of lines in England, probably half as much more: therefore £57 per mile would be practically reduced, in comparing it with English lines, to about £38 per mile per week. Now there were railways in England which had earned even more than £38 per mile per week with a single line; but he believed that was about the maximum. It was therefore not impossible that this line might pay; but the receipts, which were at present about £1,500 per mile per annum, must first be doubled. One great item in the expenses for the year 1866 was the cost of locomotive power, which had amounted to upwards of £13,000, out of a total expenditure of £25,000. On referring to the details given in the Paper, that appeared to be due, in the first place, to the high price of fuel, which cost 44*s.* 5*d.* per ton, or about five times the average that obtained in England, making the cost about 11½*d.* per mile; thus the total cost of locomotive power was given as nearly as

possible at 2*s.* 6*d.* per mile, of which the great increase was, as before stated, in coke, and the high price of labour might perhaps account for the rest. The total cost per mile for working this line would seem to be 5*s.* 5*d.*, leaving 3*s.* $2\frac{3}{4}$*d.* net profit. That was fully equal to what any English line of railway had earned as net profit per mile. In 1867 the goods traffic amounted to 37,000 tons, which was double what it was in 1866; and as it appeared that the total quantity sent to the port of shipment from all sources was more than 100,000 tons per annum, and that the imports were as large, if the great bulk of goods could be brought upon the line, there seemed to be a fair prospect that, within a reasonable time, the line would pay a moderate dividend upon the outlay, and perhaps ultimately 5 per cent.

Mr. Hawkshaw, Past President, said this railway had not been constructed for the purpose of earning dividends for a body of proprietors or a company; but it was executed by the Colonial Government with colonial funds. Therefore, although he agreed in the abstract in what had been said as to the commercial question, yet, under the peculiar circumstances of this railway, a more enlarged view must be taken. Thus the benefit to the island across which the line ran was an important element, and the results to the colony must not be neglected. As a national question, it had been too much the habit to disregard similar results in dealing with the railways of this country. If, for instance, this railway paid only $2\frac{1}{2}$ per cent. upon the outlay, it would probably pay double that to the colony; and on these grounds the Colonial Government might be perfectly justified in constructing it. The fact was, the Paper had been written some time ago, and therefore dealt with facts and figures gathered not long after the opening of the railway. It had been his duty to point out, to those in charge of the line, the necessity of reducing the staff considerably, and he believed this had been done. Again, the figures with regard to traffic and receipts at so early a period could scarcely, on a railway like the Mauritius, be a fair criterion of the ultimate results. The other, or what he had called the national question, though important, had rarely been touched upon in the Institution. He believed it would be easy to show, that the railways of this country had benefited the nation much more than the proprietors. If that were so in this country, he assumed it was likely to be the case in the Mauritius.

No one liked steep gradients and sharp curves, if they could be avoided. But the Midland line of the Mauritius railways was made over a rugged surface, rising up to a peak. The line as far as possible followed the undulations of the country; and a railway could not be constructed, at any justifiable cost across that ridge, except by steep gradients and sharp curves. In many cases, the

gradients of a railway must correspond to the natural inclination of the country, or else railways would not, from pecuniary reasons, be made at all.

With regard to the locomotive engines having eight wheels all coupled, they had been used with such success, that some more engines of the same kind were now being built by Messrs. R. Stephenson and Co. for the Mauritius. The weight was distributed in due proportion over the eight wheels, and no difficulty was experienced in working round the curves and up the gradients described in the Paper.

Mr. W. Atkinson understood that the class of locomotive engine employed on the Mauritius railways would move round curves of 200 feet radius. As it appeared from the Paper that there was no curve on the line with a less radius than 950 feet, and only one instance of that, and as none of the others had a less radius than 1,600 feet, there ought to be no difficulty on this account. He had made some calculations for ascertaining the relative commercial value of the engines employed on the Mont Cenis railway, and the original engines used on the Mauritius railways. The former weighed 17 tons, with a grip on the centre rail of 20 tons, making a total of 37 tons; while the latter were about 37 tons in weight. If there was a total rise to the summit of 1,800 feet in each direction, and if it was assumed that 1 lb. of coal in a locomotive would raise 300,000 lbs. 1 foot high, then, with three trains per day in each direction, the total quantity of coal consumed per week of six days and a half, regarding Sundays as half work, to raise 20 tons, representing the excess in weight of one engine over the other, would be 4·7 tons, at, say, £2 per ton, or £9·4. This sum, distributed over the 35 miles of railway, would be 5·4 shillings per mile per week, or only 2·7 per cent. of the total working expenses, assumed at £10 per mile per week. Now supposing the cost of the central rail to be £500 per mile, the interest on that outlay, at 7 per cent., would be 13·5 shillings per mile per week, or double the cost of raising the additional 20 tons of the locomotive. Therefore, if these figures were correct, it was clear the locomotive used on the Mont Cenis railway would not be adapted for a country like the Mauritius. As he had no information of the cost of the locomotives in each case, he had not investigated that branch of the question.

Very little recorded information was to be found about the resistance of curves. He believed it was stated in the Paper what the resistance of the train was, including the resistance of the curves, but that the amount due to the curves was not given separately. He had lately to estimate the resistance of curves in Canada; and the only information he could obtain, besides Latrobe's rules, and a formula in Molesworth's pocket-book, was derived from

an American Report.[1] This contained (at page 36) an account of experiments for determining the effect of gradients and curves, by Mr McCulloch, the General Superintendent of the New York and Erie railroad. The result arrived at was stated in the following extract :—

"The engine selected for the purpose was of the following proportions: Total weight, 66,050 lbs.; weight on driving-wheels, 40,050 lbs.; cylinders, 17 inches diameter; length of stroke, 24 inches; driving-wheels, 5 feet diameter; maximum pressure of steam on cylinders without slipping the wheels, 140 lbs.; or, deducting the atmospheric pressure, $125\frac{3}{10}$ lbs. effective pressure per square inch.

"The traction of the engine, that is, its power applied at the circumference of the wheels, and by which it is impelled, neglecting its friction, may be stated thus:

$$\frac{125\frac{3}{10} \times 17 \times 17 \times 24}{60} = 14{,}485 \text{ lbs.}$$

"This is the total resistance, consisting principally of the friction of the engine and tender of the cars, the gravity of the train on ascending grades, and the resistance of curves which this engine, under an effective pressure of $125\frac{3}{10}$ lbs. per square inch upon its pistons, can overcome.

"The engine and tender were moved with slightly accelerated motion, on a level, under an effective pressure of 3 lbs. Their friction, therefore, without any load attached, is

$$\frac{3 \times 17 \times 17 \times 24}{60} = 347 \text{ lbs.}$$

"It has been customary to estimate the friction of cars, with wheels of 30 inches and journals of 3 inches diameter, at about 7 lbs. per ton; or 8 lbs. per ton for wheels 33 inches and journals $3\frac{7}{8}$ inches diameter—the dimensions of those in use on this road; but the experiments made show conclusively that the friction of the loaded cars did not exceed $4\frac{1}{2}$ lbs. to 5 lbs. per ton.

"It has also been usual to estimate the additional friction of the engine, in consequence of its load, at 1 lb. per ton of its load on a level. This item will, of course, be reduced as the friction of the cars is reduced.

"After a careful examination and comparison of the loads moved upon the ruling grades and curves of various sections of the road,

[1] *Vide* "Report of Lieut.-Col. James H. Simpson, Corps of Engineers, U.S.A., on the Union Pacific Railroad and Branches, Central Pacific Railroad of California, Northern Pacific Railroad, Wagon Roads in the Territories of Idaho, Montana, Dakota, and Nebraska, and the Washington Aqueduct. Washington, 1865." [Inst. C.E. Tracts, 8vo., vol. 170.]

it is assumed that the friction of the cars is $4\frac{1}{2}$ lbs. per ton of 2,000 lbs.; the resistance of curves $\frac{1}{2}$ lb. per ton per degree of curvature per 100 feet; and the additional friction of the engine $\frac{1}{2}$ lb. per ton of load on a level and straight line, or its equivalent.

"The weight of the engine on its drivers being 40,050 lbs., and the traction 14,485 lbs., the adhesion was, therefore, $\frac{14485}{40050} = \frac{36}{100}$, or not less than 36 per cent. of the insistent weight.

"This has heretofore been variously estimated at from $12\frac{1}{2}$ to 25 per cent.

"The tender, with its complement of wood and water, weighed 40,240 lbs."

The resistance of the curves given in this extract agreed, under certain conditions of length of train, with the results derived from the rules of Mr. Latrobe and Mr. Molesworth.

Mr. J. W. Barry remarked that it was unfortunate the Author of the Paper should have mixed up the capital cost of the North line with that of the Midland line, as it produced confusion in the endeavour to arrive at a conclusion as to the commercial results of the Midland line. The average of nearly £22,000 per mile was arrived at by taking the whole cost of the two lines, and dividing it by the whole mileage in the island, which was 66 miles. If, then, the receipts per mile on the Midland line were considered with reference to the average cost per mile of the two lines, incorrect results would probably be obtained. The results of working the North line had not been given, but only those of the Midland line. With regard to first cost, it must be recollected that the land appeared to be exceptionally expensive for a colony, having cost the large sum of £3,000 per mile. Moreover, the expenses of raising the Government loan had been added to the cost of the railway, and a very expensive terminal station had likewise been included.

Reverting to the subject of the engines in use on this line, which had been somewhat severely criticised, he thought the weight on each pair of wheels was not excessive, and the report of the officers intrusted with the working of the railway was that the engines were satisfactory, and passed easily round the curves. If a line like this, with steep gradients of 1 in 27, or 1 in 30, had to be worked by ordinary locomotives, it was obvious that heavy engines suitable to such inclines must be employed. It had been suggested, in the course of the discussion, that instead of one heavy engine, two lighter locomotives should be employed—one in front of each train and one behind. It seemed to him, that was a fallacy. By referring to the Paper it would be found that salaries and wages amounted to 6*d.* per train mile. If two engines were used, this item of expenditure would probably be doubled. Again, the wear and tear would be for two engines instead of for one, and certainly

there would be no diminution in the fuel consumed; so that instead of the working expenses being 5*s.* 5*d.* per train mile, as at present, they would amount to at least 5*s.* 11*d.*, or 6*s.* per train mile. It was true in the case of a railway with generally good gradients, and with only one or two steep inclines, a bank engine could be used economically. That, however, was not the case with the Mauritius Midland line, for it consisted almost entirely of steep gradients; and any engine which pushed a train up to the summit would have to go down again to the level of the sea to push up another. As the summit was about midway between the two termini, the proposal amounted to every train having two engines for its entire journey, thus largely increasing the locomotive expenses, which were already very heavy. It might be useful to compare the working expenses of this line with those of another colonial line—the Cape railway. That railway cost £12,000 per mile, and the receipts per mile per week were £15, against about £25 on the Mauritius line. The working expenses per train mile on the Mauritius were 5*s.* 5*d.*, or 62½ per cent. of the gross receipts; and on the Cape line, 5*s.* 3½*d.*, or 68 per cent. of the gross receipts. Looking to the larger Mauritius traffic per mile per week, and recollecting that the fixed charges on a railway, which formed a considerable proportion of the whole working expenses, did not bear much direct relation to the amount of traffic, it seemed the working expenses of the Mauritius line, with gross receipts of £25 per mile per week, were high. To compare these railways with English lines, it was necessary to recollect that in most cases of colonial lines there were no Government duties, and no rates and taxes to be paid, and no annual parliamentary expenses to be met. It would be interesting to know how the Mauritius line was situated in this respect. Taking the case of the London and Brighton railway, he found by the accounts just published for the first time in the form prescribed by the Board of Trade, that the Government duties and rates and taxes amounted to no less than 5½*d.* per train mile, while the total working cost was 3*s.* 2½*d.* per train mile. These home burdens, therefore, amounted on the Brighton railway to upwards of 14 per cent. of the gross working expenses. On the other hand, though the colonial lines were perhaps for the most part exempt from expenses corresponding to these burdens, yet the cost of conducting any enterprise by English labour in a foreign country must necessarily be great. As a rough approximation, it appeared that the working expenses of the Mauritius and the Cape railways were something like twice those of an English line, after deducting the Government duty and rates and taxes. It was right, when the public complained of high fares on the English lines, that they should be reminded that more than 14 per cent. of the gross working expenses were contributed to the public funds.

Mr. W. H. Barlow considered, that no proper comparison of receipts and expenditure could be made between a line running two or three trains each way per day, and one like the Brighton, running fifty trains per day. It was known that on all railways one large element of expenditure was of a fixed character, and the other was variable according to the traffic. It was therefore impossible to draw accurate conclusions by taking the train mileage, or per-centage, between a line which had a small amount of traffic and one which had a large amount of traffic.

Mr. Berkley observed that the special object of the Paper appeared to be to open a discussion upon the working of steep inclines on railways. Before entering on that question, he expressed a hope that some information would be supplied as to the cost of materials, labour, and fuel in the island, as also the general character of the works of the railway, and the physical conditions of the country.

The Author of the Paper had perhaps been unfortunate in the expression that, "the severity of any gradient for a long line should never exceed 1 in 40." Undoubtedly, as had been said in the course of the discussion, no such limit could be fixed. The determination of the gradient must depend upon circumstances, perhaps chiefly on the amount of the traffic and the comparative cost of construction. Those who had inspected the working of inclines, as he had done in many parts of the world, would probably conclude with him, that the Author was not wrong in saying, that if at a reasonable cost, a gradient of 1 in 40 could be obtained, it was undesirable, on account of the difficulties of working steep gradients, to adopt a steeper gradient. Of course it might be said, indeed in effect it had been said, that an increased gradient might be better, because then some other system suitable to working very steep gradients would be devised, or because the ingenuity of mechanics was such that engines would be produced to overcome the difficulties. This statement was made to excuse the adoption of an inferior gradient, and added to other conditions, it might possibly in certain cases amount to a justification. It should, however, be always remembered, that the adoption of a superior gradient required neither excuse nor justification.

The following statement would illustrate the effect of gradients in limiting the traffic which could be carried, and adding to the working charges. The power of the engines working the inclines was the same on the Mauritius, the Semmering, and the Indian Ghât inclines. The engines had cylinders 18 inches in diameter, with a length of stroke of 24 inches, and eight coupled wheels, each 4 feet in diameter. It was stated in the Paper that on gradients averaging 1 in 45, the steepest being 1 in 27 and 1 in 30, this class of engine propelled ordinarily up these inclines

passenger trains of 42 tons, and goods trains of from 100 tons to 120 tons. On the Indian inclines, engines identical with these propelled passenger and goods trains, of 150 tons to 160 tons, up gradients of 1 in 37. On the Semmering, with gradients of 1 in 40, the passenger trains averaged 130 tons, and the goods trains 175 tons, and were occasionally as heavy as 200 tons. He believed the great difficulty in working steep gradients was not in ascending, but in safely descending the inclines. He was not able to give any further information with respect to the recent accident on the Bhore Ghât incline. It appeared that, with the full ordinary amount of break power on the engine and carriages, the train did overpower the breaksmen, and was precipitated over the end of the reversing station. The reversing station was a piece of level line, like the stem of the letter Y, into which the train was placed after ascending up one branch of the letter, while the engine was moved from one end of the train to the other, so as to be in the proper position to propel it up the other branch of the letter Y. It might be interesting to know the amount of break power which was desirable on inclines of this character. Some accidents had happened from the want of sufficient break power; it was therefore a matter of interest. It was stated that on the Mauritius line the train had overcome the breaksmen four times, and although no serious accident happened, unfortunate consequences might have resulted on such occasions. On the Semmering incline of 1 in 40, and on the Giovi of 1 in 36, and of 1 in 27 for a part of its length, the rule was to have one break to every two carriages in passenger trains, and to every four vehicles in goods trains. The break was applied to all the wheels of the vehicle to which it was attached. On the inclines in India the rule was to have four special break-vans and two ordinary break-vans to each train of sixteen carriages; or about one break-van to every three vehicles.

Much had been said upon commercial questions, and on the comparative cost of working the railway under consideration. He thought there was not sufficient information to enable an opinion to be formed on this subject. It seemed, however, to be agreed, that it was impossible to make any comparison between the working cost of this line and that of a line situated in England, or indeed in any country where all the circumstances were so different.

On the subject of catch sidings, his impression was that, if made in connection with the descending line, and to rise in an opposite direction, so as to absorb the momentum acquired by the train in descending the gradients on the main line, the addition of risk involved by putting in meeting points on the main line of the incline would be greater than any saving of risk which might result from the catch sidings.

The position in which the engines should be placed in the trains

was a matter of importance, because accidents had arisen in some cases from placing the engine behind the train, and in other cases from the end of an ascending train breaking away from the leading part. The rule observed on the principal lines, where the gradients were steep and the curves of short radius, was with passenger trains to place the engines in front. This did not apply to goods trains, where the load was very heavy, and at starting liable to break the couplings. Then there was danger of accident from the detached portion descending the line by its own impetus, and coming in contact with a passenger train that might be following it. In such cases it was almost universally the practice to place an engine at the rear of the train—proper precautions being taken in making-up the train, by placing long vehicles, like timber-trucks, &c., near the leading engine, to prevent such vehicles being pushed off the line by the pressure from behind.

He would now state some facts relative to engines which he saw in 1864 successfully used on two or three inclines—special engines adapted to special circumstances. He did not refer to such inclines as that which passed across the Alleghany mountains, where a powerful goods engine was used. The gradient of that incline was 1 in 60, and though that might be regarded as an incline, the working of it was not varied in a material degree from the other parts of the line. On the Giovi incline there were two classes of coupled engines, some with four wheels, but the majority with six wheels, because those with four wheels were not found to be so powerful as was desired, and the weight on the wheels was destructive of the permanent way. The six-wheeled engines were worked in pairs by one driver and two firemen. Their weight was about 36 tons, and each had a tractive force of adhesion of 10,000 lbs. to 10,500 lbs., taking one-seventh of the weight for adhesion.

On the Semmering, several classes of engines were employed. One class was tried which had all the ten wheels of the engine and the tender coupled and used for the purpose of obtaining adhesion; but the complication was such, that the connection between the engine and the tender was broken, and the engine-wheels alone were coupled. This engine was not satisfactory, as although it weighed 59 tons, and the tender weighed 21 tons in addition, only the same force of adhesion, about 10,500 lbs., was obtained as with the 36-ton engines on the Giovi. This led to the construction for the Semmering incline of another class of engine, with eight wheels coupled, and weighing 47 tons, or, including the tender, 66 tons. With this a power of traction by force of adhesion was obtained of about 15,000 lbs. The engines described in the Paper were of precisely the same dimensions, and within a ton of the same weight as those used on the Indian lines, which had cylinders

18 inches in diameter, with a length of stroke of 24 inches, and eight wheels coupled, each 48 inches in diameter; and these engines weighed 49 tons in working trim. Engines of these dimensions, with an average effective pressure of steam in the cylinders of 100 lbs., would give out at the periphery of the wheels a tractive force of about 16,300 lbs. The resistances on a gradient of 1 in 37 were equal to about 70 lbs. per ton. On this gradient, therefore, these engines should propel a total load of about 230 tons, or a net load of 180 tons, being about four times their own weight. In practice, trains weighing 160 tons were propelled up this gradient. These engines had worked very satisfactorily for some years, and easily passed round curves of 20 chains' radius. They had a lateral play of 1 inch in both the leading and the trailing axle-boxes, which were arranged as follows:—The bearing-steps fitted the journals, but on the top of the axle-box there were six inclines, three on each side of the centre line. Of these the two outer inclines on each side had an angle of 1 in 8 descending from the centre of the box, while the two centre inclines had also an angle of 1 in 8, but these descended towards the centre of the box. A steel plate carried the spring piece, and had inclines on its under side which rested on the inclines on the top of the axle-box. The axle-box had a side play in the axle-guards. The effect of this arrangement was, that when the engine entered a curve, the axle-boxes slid under the steel plate which moved up the inclines, and when the engine returned to the straight line, the motion was that of sliding down the inclines to the normal or central position. This simple and excellent arrangement was introduced on the Great Indian Peninsula railway more than ten years ago by the late Mr. Cortazzi, who was then the Locomotive Superintendent. His impression was that the class of engine on the Giovi, used either in pairs or singly, and the eight-wheeled coupled engines on the Mauritius line, and the same class on the Great Indian Peninsula railway, were the best practical engines for working such inclines. Statements were often made respecting the extraordinary merits of certain engines; but he almost invariably found, that such reports proceeded from a line where the Superintendent had an interest of some kind in such engines. There was a natural bias in the human mind in favour of that which one invented, or had an interest in. From what he had seen and read on this subject, he was convinced there was not much difference between any of the classes of engines, which were simple in construction, strong, utilized all their propelling power by the force of adhesion, and did not carry too great a weight on any one pair of wheels.

Mr. R. P. Brereton thought the question of danger in working such inclines might be dismissed from consideration, inasmuch as the Mauritius railways had been opened for three or four years,

and no accident had occurred, and there were only four instances of trains getting for a time beyond control. With regard to the subject of breaks, he had had an experiment made after the accident at Abergele, which justified the conclusions he previously entertained. The breaks upon the guard's van behind an ordinary goods train were put down and screwed hard and tight, and the van was then left standing upon the line while the breaking up and usual shunting of the train proceeded. He found, after two or three blows and jerks, such as were given in shunting by the backing of the engine, that the break-blocks ceased to nip the surface of the wheels, and did not prevent the wheels from turning. He had no doubt the guard might have gone away from the train in the belief that the breaks were acting perfectly throughout, whereas, after two or three blows, the nip between the break-block and the wheels had ceased. Where there was so little room for elasticity between the surface of the block and the break-screw, one or two turns were sufficient to wear and liberate the wood; and there was nothing to cause the handle or the break to follow up, as with the ordinary weighted lever break. With regard to the engines on the Mauritius railway, he could not understand how, by merely altering the lead of the slide-valve $\frac{1}{8}$ of an inch, 10 per cent. was added to the power of each engine. He should be glad to know what had led to the suggestion that produced such a result, for it was extraordinary that such an improvement could have been neglected by the eminent makers who had had from thirty to forty years' experience.

Colonel Morrison (Surveyor General of Mauritius) said that, personally, he had had nothing to do with the construction of these railways; but so far as the line of country through which they passed was concerned, he might say that, in many parts, it was one which presented considerable difficulties. Generally, the excavations had been made through hard blue basalt, volcanic rock, and a solid description of clay, called 'tufa.' The ravines were in some places deep, and liable to sudden flooding; the ground was in many localities not only thickly covered with forest, but there was an extensive undergrowth, amongst which a species of wild raspberry—the framboise de Chine—abounded, a thorny bush which occasioned great difficulty in opening out the line, and through which the Coolies could but slowly cut their way. With regard to the expense which had been incurred for the construction of the Northern and the Midland railways, it should be borne in mind that it was originally intended that there should be two independent lines, each starting from its own terminus in Port Louis, when the total cost would probably not have been more than £15,000 per mile, in lieu of that given by the Author. But it was subsequently determined to connect the two

lines by a central, or Town, line, and an enormous portion of the actual expenditure for the railways was due to the construction of this line, which, though not much over 1 mile in length, passed through a very important part of the town. And, if the contemplated conversion of the Caudan Basin into a dock was carried out, much additional expenditure must be incurred. In framing the estimates for the cost of the railways, Colonel Morrison believed a considerable sum had been included for the importation of labour from India—something like £60,000; and large as the amount might appear, it was much to be doubted whether Mr. Longridge could have been certain of obtaining in Mauritius, at all seasons, labour sufficient to carry on the works at a rate of progress in accordance with the contract. The land in the country, it was believed, had cost a great deal more than should have been paid for it; whilst the expense incurred in purchasing the ground for the Town line, in compensation for destruction of buildings, in filling in and building in the Caudan Basin, in the useless diversion of the Pouce and Tonniers streams, in the subsequent reopening of their old channels, &c., had been very great. He recollected that, on one occasion, Mr. Longridge, in alluding to the cost of the land, had remarked that some of the planters had stated that they would make a present of their land to ensure so great a benefit to the island as the construction of railways; but when the time arrived for the fulfilment of this patriotic arrangement, their feelings of liberality had completely vanished. In framing the estimates, however, Colonel Morrison doubted whether any portion of the land required had been put down under the head of 'gratis' by Mr. Longridge.

As to the traffic of these railways, it must be borne in mind that there were many causes which operated at first, and, in fact, for some time, against large receipts. The mass of the inhabitants of Mauritius had never seen a railway, and at first a dread was entertained, by a numerous class, of the gradients and of the Grand River Viaduct on the Midland line. Many of the planters, too, were unwilling, or unable, to avail themselves of the lines at the times they were opened. The cost of transport was considered too high in most cases; whilst there were few of the planters who had not previously made their arrangements for the conveyance of the sugar crop by their own carts and mules into Port Louis, or by the native coasters where the estates lay near the coast. For many months the railways met with a determined rivalry from such transport, and for some time it was impossible that it should be otherwise. Such mules and carts as were not required for the 'entrecoupe,' or had been rendered necessary for the conveyance of the crop, could not have been all at once offered for sale, or otherwise disposed of, nor could purchasers have been readily

found for the whole of the coasters. The only plan by which the traffic could have been brought to the railways would have been to have fixed the rate of transport so low as to have run the carts off the road, and rendered the use of the coasters unprofitable. And such a course would, he believed, have been good policy, even though it must have entailed temporary loss to the railways. As time passed and the traffic augmented, it was found that there were not always a sufficient number of wagons, nor sufficient locomotive power; and it was only by degrees that the planters could be brought to consider, as alterations in the rates for carriage of goods were made, the railway the cheaper means of transport. Then, too, a succession of annual droughts, disease amongst the canes, the ravages of the 'Poublanc' and the 'borer,' &c., had severely injured the sugar crop in various parts of the island; whilst in the northern and eastern districts the cultivation of considerable tracts had been abandoned. Each year produced a smaller crop than its predecessor; and one need not, therefore, be surprised, that the amount of traffic on the railways had been much less than it might have been, for the main dependence of the railways for revenue was unquestionably upon the sugar crop. If, from any cause, the crop should be much reduced, or be destroyed, the revenue of the railways would be almost gone; for the failure of the crop would not alone reduce the goods traffic, but, as every interest in the island would suffer from the deterioration or ruin of the staple produce, passenger traffic would certainly be lessened in a proportionate degree. This latter traffic, too, would, from the character of the general population, be seriously affected by any bad accident upon the railways; the effect would be much greater than would be produced from a similar accident upon any English line. The safety hitherto enjoyed certainly reflected the greatest credit upon Mr. Fisher, the original, and Mr. Mosse, the present, General Manager.

As regarded the working expenses, they must, it was feared, always amount to a high per-centage of the receipts; and, in fact, they would seldom, if ever, be less than 60 per cent. There were various circumstances which tended to make the working expenses high. Labour, skilled and unskilled, and fuel, were very expensive; carpenters, masons, and blacksmiths were paid from 3*s.* to 4*s.* 6*d.* per day; foremen, 6*d.* to 1*s.* extra; labourers from 1*s.* to 1*s.* 3*d.* a-day, exclusive generally of hutting, rations, and medical attendance; and the amount of work performed was only about equal to one-half that of an ordinary European, excluding from consideration such labour as that of railway navvies. Creole and Indian workmen required very sharp supervision, and their foremen were frequently as lazy as themselves. Engine-drivers and other Europeans were highly paid, but then it must be re-

membered that Mauritius was an expensive colony. The wear and tear upon such a line as the Midland must be great, and the repairs in a tropical climate were always liable to be much heavier than in a temperate climate. The main dependence, as had been already stated, of the railways for revenue was upon the sugar crop, the transport of which extended only over four months or five months of the year, after which a large portion of the rolling stock was really not required, and the outlay upon which was comparatively unremunerative during the remainder of the year. Should sickness, such as the dreadful fever of 1867, make its appearance, the price of such labour as could be obtained for current repairs would be much higher, not only from the diminished number of labourers, but from the smaller quantity of work which might each day be performed by an enfeebled class of workmen. During the crop season there was frequently a great demand for labour of all kinds amongst the planters, and the high wages, which, for a time, were paid, had sometimes the effect of creating a serious rise in the price of labour. Coal, too, was expensive, costing generally from £2 to £2. 10*s.* per ton. All these causes tended to maintain the railway expenses at a high figure, and no comparison, as it had been attempted to institute, could really be drawn between railways in Mauritius, where there was but one town of any importance, but one single article of produce was raised, and the traffic was intermittent, and English railways having a constant traffic, as regarded every description of produce throughout the year, and uniting large towns and cities, between which there was constant communication. After a few years' working, especially upon such gradients as those of the Midland line, provision would probably have to be made for the renewal of rails, sleepers, engines, &c., at no inconsiderable expense.

As far as he was capable of judging, from merely travelling over the line, the works had been carried out in a fairly substantial manner, with the exception of the station-master's quarters, booking offices, &c., at the several country stations, which were generally of a poor construction, and not well suited to a tropical climate. The accommodation, too, of the waiting-rooms, was often of an inferior description, various platforms required to be lengthened, and several of the goods sheds should have been much larger.

But there was a serious question as to the propriety of making the railways at all. For his part, he thought that their construction had never been really needed. The island had only an area of about 700 square miles. It possessed no large towns or villages (with the exception of Port Louis) between which any traffic could be established. The island laboured under the serious disadvantage

of being dependent for its prosperity, he might almost say for its existence, upon one article of produce, any failure in which would seriously affect the one great source of revenue of the railways; whilst the working expenses could not be reduced to any great extent, and the heavy fixed charges for forming a sinking fund and payment of the annual interest upon the money borrowed had still to be met. Whatever facilities it might be thought existed for locomotive traffic in certain portions of the island, by reference to the map (Plate 12) it would be seen that there were large tracts which were but little, if at all, benefited by the construction of railways, whilst the main roads had still to be maintained, and many others constructed and maintained to feed the railways. No doubt a considerable improvement had been created, so far as individual comfort was concerned, in being able to travel by these railways. But when it was remembered that these railways had cost nearly a million and a half sterling, that a heavy outlay must yet be incurred, if the dock in the Caudan Basin, and other works,—not to speak of branch lines which the inhabitants of Moka and Savanne had been desirous of seeing constructed—were to be executed; and when it was considered how heavy must be the working expenses, to what great diminution of receipts the revenue might be subject in its dependence upon one single article of produce, the heavy annual provision for sinking fund and interest, it was much to be doubted whether the accommodation for goods and passenger traffic now provided was worth the outlay which had been, and must be, borne by the colony. Colonel Morrison thought the inhabitants would have done better to have remained contented with the ordinary roads, which might have been fully provided for the whole island for one-fourth of the cost of the railways, and maintained at a small expense compared with the annual expenditure upon the railways. In making these remarks, however, it was not so much for the purpose of criticising what had been done in the colony, as to suggest the consideration, how far the construction of railways was judicious in places where area, population, produce, facilities for locomotion and traffic, cost of construction and maintenance, were similar to those of Mauritius.

Mr. Fell said, the question had been raised, as to whether the central rail engine, or the ordinary locomotive, was the more profitable for working inclines of 1 in 27. He would give reasons for believing that, under certain circumstances, the central rail system was preferable. It had been implied that the gradient of 1 in 27 did not warrant the additional outlay for the central rail, and if so, it was clear, that was a case in which it ought not to be used. It had been asserted in the course of the discussion, that there were instances in which the worst gradient might be considered the best in its results, and he wished to bring forward some facts to show

that it might be so, and for that purpose he would refer to an extreme case, as an example, that of the Mont Cenis line. That railway was worked with engines of a special class, which probably cost more for the same amount of tractive force than other engines, but they performed a special service which could not be performed by ordinary locomotives. Those engines could be made to work the trains over the Mont Cenis at a cost of 4*s.* 6*d.* per train mile, as the cost of working simply, to which must be added 3*s.* for interest on the capital employed, making a total of 7*s.* 6*d.* per train mile, the receipts being 12*s.* 6*d.* per train mile in that case. Comparing that with the great tunnel line, which, when it was opened, would cost 130,000,000 francs, and supposing five hundred train miles per day were run, then the cost for interest of money, exclusive of the working expenses, would be 33*s.* per train mile. The cost of working would however be reduced from 4*s.* 6*d.* to 3*s.* per train mile, because in the tunnel line there was a summit of only about 2,500 feet to overcome, as compared with 5,000 feet on the Mont Cenis summit line. Therefore he put down the 33*s.* interest on capital, and 3*s.* per train mile for working expenses, making a total cost of 36*s.* per train mile for the tunnel line as against 7*s.* 6*d.* per train mile on the summit line. That was calculated on a traffic of five hundred train miles per day on a line 50 miles in length, and to make the cost of interest and of working expenses the same in both cases, it would require an increase in the traffic of sevenfold what had been assumed, in order that the cost of carrying traffic on the tunnel line should be equal to that on the summit line. He thought it was hopeless to expect, that the traffic over any one Alpine Pass would be increased to that extent; therefore he said this was a case in which the worst gradient was obviously the best in a commercial point of view. There was also another question of importance, which should not be overlooked at a time when the public were reluctant to embark in railway investments—that was, the financial question. It was difficult to raise money for any railway now, and if the public were asked for ten millions instead of one hundred and thirty millions for any undertaking, the money was much more likely to be raised and the line to be made.

Mr. Bidder, Past-President, regretted that a subject of the utmost importance had been raised in what he considered an imperfect manner. He thought the great question of the working of railways, and the policy pursued with regard to gradients, maintenance, and renewals, was one which ought to be discussed thoroughly and entirely at the Institution.

He did not think the commercial question was raised at all in relation to the Mauritius railways. In looking at a national object they had no right to regard the per-centage of earnings: at the

same time, a railway made for national purposes might no doubt be made to pay a good dividend. The results which had attended the vast railway system of this country were well known. Many companies had been brought to ruin; the greater portion received an inadequate income; and upon the whole capital embarked the average dividend was not more than 3 or 4 per cent. He had investigated what the worth of the railways was to the country, and he believed it was a tolerable approximation when he stated, that the railways made a return to the national exchequer of 15 per cent. It was true it might be said if the railways did not exist, the present amount of traffic would never have been created; but that was no answer, for it might be that the traffic was worth more than the actual amount of carriage which it produced to the railways.

The question of gradients had been referred to. For the last forty-five years he had been more or less engaged in giving evidence before Committees of Parliament on this subject. It began with the old Liverpool and Manchester line—how to get up 1 in 50. It was matter of contest with the Great Western and the London and Brighton, and again in the last instance in the proposed London, Lewes, and Brighton line. Luckily for this country, the original locomotive engines used on the London and Birmingham railway, averaged only about one-eighth of the power of those at present employed. The old engines were incapable of dealing with the ordinary traffic even at a slow speed; and he had seen, on the London and Birmingham line, three engines attached to an ordinary passenger train, under exceptional circumstances, to enable it to attempt to keep its time. The result was, gradients were measured by a few feet per mile. The prevailing gradient of the Great Western was 8 feet per mile: that of the London and North Western was 16 feet per mile; and the principal railways had been constructed with those flat gradients, which, though even when obtained at a cost beyond their worth, he believed had been fraught with the utmost advantage to the prosperity of the country.

In the case of a railway with a preponderance of passenger traffic, there might be some justification in having a gradient of 40 feet per mile; but for heavy traffic, at high speeds, it was worth while to incur additional expenditure for the sake of obtaining the best ruling gradient that the country would afford. In the year 1835 he made a survey for the railway between London and Brighton; and about the same time a learned philosopher and an able writer favoured the public with an essay upon railways, in which he laid down seventeen plain rules for the guidance of Parliament. It so happened that the line he was connected with, between London and Brighton, had gradients of 16 feet per mile, no curve less than 1½ mile radius, and only two tunnels of about 300 yards in length

each. It was well supported in the City (there was no financing in those days), and eventually the Bill came before Parliament, in opposition to what was called the Direct line, which was the line ultimately made, and now passed over with so much satisfaction. This Direct line was 4 miles shorter; but it had gradients of 20 feet per mile against 16 feet per mile, and besides, there was the Croydon incline and a long tunnel. At that time, he would mention, the Committees of the House of Commons were not composed of four or five Members only, but consisted of a panel of Members selected from the counties and towns through which the line passed; and in the House of Lords the Committees were open, and every Member of the House of Lords was entitled to attend and vote. The argument on behalf of the opposition was that a line 4 miles shorter must be the more advantageous of the two. That was all very well; but a gradient of 16 feet per mile was better than one of 20 feet per mile. The bill was passed by the Commons; but when it went to the Lords the circumstances were very peculiar. The Committee was attended by fourteen peers. He should, in passing, mention that the learned writer who laid down the seventeen plain rules for the guidance of Parliament, was a supporter of the original Direct line to Brighton, which was antagonistic to that with which Mr. Bidder was connected. Singularly enough, this Direct line violated sixteen of the seventeen rules so laid down; and the consequence was, before going to the House of Lords, a subsequent edition of this book was published. After an investigation of nine or ten days before the Committee of the House of Lords, he thought a strong case had been made in favour of the line he had surveyed, and felt assured that, out of the fourteen peers, thirteen would vote for it. The only one who opposed it had a local interest. The matter came to the stage where the preamble had to be voted upon; and on that morning a well-known personage of those days made overtures to the chairman of his company; but these were not accepted, and the result was that a quarter of an hour before the vote was taken, in walked twenty-eight peers, and the preamble was declared to be lost by a vote of 29 to 13.

With regard to the great and important subject of railway policy, there was the question of closing the capital account. If that meant that a company had determined to make no more railways or branches, he could understand it; but if it meant that under no conditions whatever was the capital account to be increased, then he thought it was sheer nonsense. To take an extreme case—and he did so because it was from such examples that the tendency of things could be best seen,—suppose the traffic of the London and North Western railway to be doubled, and that the returns were six millions a year in excess of what was at present taken—that six millions of traffic would necessitate additional rolling stock,

larger stations, and a probable outlay of ten millions. If the capital account was to be closed, then for three years no dividend would be paid, though such traffic would bring three millions more net revenue, and add sixty millions to the value of the undertaking. Now, considering the class of persons who held that property, such an act as that would be one of confiscation.

Then again, there was the question, under what circumstances and conditions could branch lines and extensions be usefully and beneficially undertaken? And again, the connection between the Government and the railways, on which extreme opinions existed. There were those who thought that the Government should take the railways into their own hands, as they had done the telegraphs; while others considered it better that the railways should be independent of the Government. His own feeling was that an intermediate course might be taken with advantage to all parties. The discussion which took place at this Institution on the Atmospheric Railway,[1] if it did not entirely prevent the waste of capital in the attempt to carry out that system, certainly lessened the expenditure that would otherwise have been incurred; and he believed there never was in the Institution a more useful discussion, or one which had been more practically beneficial.

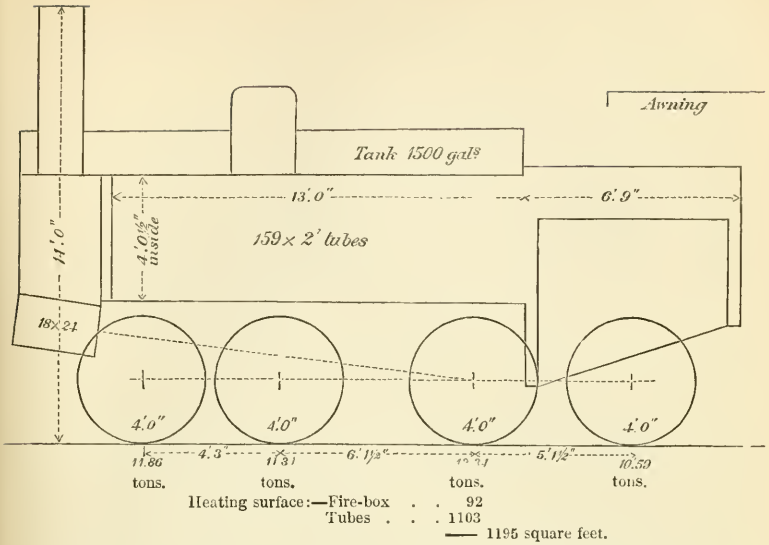
Mr. Mosse's Paper had opened up another point which was introduced by Colonel Morrison, who seemed to be under the impression, that Mauritius being an island rather less than 40 miles in extent, with a rough surface, the money expended on the railways would have been more usefully laid out in perfecting the ordinary roads. Looking at the district passed through, and the sparse populations in immediate contiguity with the railways, he thought it probable that the improvement of the roads of the island might have given greater general accommodation, and have produced a better effect than a railway through one part of the island only. He readily conceived that might be the case; therefore the remarks he had made as to the advantages of railways generally must be taken as being to a great extent governed by the questions of common sense and commercial requirements.

Mr. Hawkshaw, Past-President, said the estimate for the North line was £342,530, and that for the Midland line £434,131, making a total of £776,661, and he believed those estimates had not been exceeded, in any appreciable degree, so far as the works were concerned, and that the colonists voluntarily entered upon this expenditure. The ultimate total average cost of £21,876 per mile was due to other causes. There was what was called the Town line, about 1½ mile in length, which was projected by the

[1] *Vide* "The Peculiar Features of the Atmospheric Railway System," by G. Berkley. Minutes of Proceedings Inst. C.E., vol. iv., p. 251.

colonists themselves, and with which he had nothing to do excepting to direct the works. That line was very costly, but whether profitable or not it was a matter for the colonists themselves. Again, the land, which it might have been supposed in a colony like Mauritius would have been obtained for a small sum, had cost £195,144. The general opinion appeared to be that the price paid for the land was excessive; but it was a matter over which an engineer had no control. Then labour had to be imported to such an extent that a sum of £64,000 was put into the original contract for this contingency. If railways were made where labourers were scarce, it could not be expected that the work could be executed at a small cost. The wages of carpenters ranged from 3*s.* to 4*s.* per day; of masons from 3*s.* 6*d.* to 4*s.*; blacksmiths 3*s.* 6*d.* to 4*s.* 6*d.*; Creole fitters 3*s.* 6*d.* to 6*s.* 6*d.*; and labourers (exclusive of rations, &c.) 1*s.* 2*d.* to 1*s.* 6*d.* per day; and though these wages might not appear excessive, it must be taken in connection with the quantity of work done per man, which was small. The average amount of earthwork excavated per man per day was about $1\frac{1}{4}$ yard, and the average amount of embankment from the loose soil and stone of adjacent fields was about $1\frac{1}{2}$ yard per man; so that the labour was in fact costly. With regard to the working expenses of the line per train mile, no doubt they were heavy; but coal cost 45*s.* per ton, the wages of drivers and of skilled labour were high, and the per-centage of working expenses, as stated in the Paper, had not much bearing on the question, because that depended upon the amount of the traffic. On this line the traffic had hitherto been limited—first, because the line had only recently been opened; secondly, on account of the extraordinary mortality which occurred in the island, and which in Port Louis alone averaged as many as 207 per day—a rate sufficient to have exhausted the whole population of the island in a year or two; and, lastly, the island had been visited by one of the most terrible hurricanes ever experienced, which destroyed the crops, and a large number of buildings. These calamities, occurring almost simultaneously, were certain to diminish the traffic. The weight of the eight-wheeled coupled locomotive engines was 46 tons and not 48 tons. Fig. 1 showed the leading dimensions and form of these engines, and the way in which the weight was distributed, from which it would be seen that the weight upon any pair of wheels was in fact less than was common in this country. He certainly could not explain how it was that an alteration of $\frac{1}{8}$th of an inch in the lead of the slide-valves should have increased the power of the engines 10 per cent., and he was very doubtful about the fact. In the first place it could not be done unless the power of the engine previously was less than the amount of adhesion, which he doubted.

Fig. 1.



The Author had expressed the opinion, that for a long rise no gradient should be steeper than 1 in 40, and, on the other hand, in the course of the discussion Mr. Longridge had alluded to gradients of 1 in 12. On the subject of gradients, without attempting to enter at present into the large question which Mr. Bidder was desirous should some day be discussed, he would say he should be sorry if any precise rules were laid down either about curves or gradients. Attempts had been made to do so for the last thirty years. He remembered the time when, in the House of Commons, it was urged that trains should not be taken round curves of 40 chains' radius faster than a limited speed per hour: and he also remembered when it was said that locomotives ought not to be employed for gradients steeper than 1 in 50. All these propositions were hourly set at nought: and he trusted no attempt would now be made to lay down such laws. The fact was, all these questions were matters of experience, and it was the duty of the engineer to consider the particular circumstances and physical features of the country where railways had to be constructed, and then to devise that mode of construction which was the cheapest and the best for those circumstances and for that country. It was idle to say, if railways were wanted in a country the surface of which was like a pyramid, that the lines must not pass over its surface, more especially if the population lived there; and if the lines did pass over the surface, then the gradients must conform to the natural configuration of the country. Whatever discussion

was entered into, either now or at any future time, he should strongly object to any one laying down rules which would cripple and check the inventive talent which had made railways what they were: what they might be ten or twenty years hence no one could pretend to say.

Mr. Gregory, President, said, in the face of the extreme interest of the subjects which the Paper had opened, he regretted that the discussion upon it must be closed. Under the circumstances he would not attempt to sum up the discussion: and, indeed, much that he might have said had been anticipated by those who had spoken. While interested in the discussion that had taken place on the effect of gradients on the working of railways, that subject had been by no means treated exhaustively; and he was sure all would agree with Mr. Bidder, that there was still a large field of discussion open connected with railway operations, in the Economy and Politics of Railways. It must not, however, be attempted to crowd too much into one Paper. There were some branches of those subjects which could be treated by Mr. Bidder with an ability to which few could hope to attain; and he hoped that gentleman would carry out his own suggestion, by favouring the Institution with a Paper on one or other of those important questions. Meanwhile, there were many members who must have valuable experience as to the effect of gradients upon the working of railways. He was lately looking through the Minutes of Proceedings of the Institution, and he found the information on that subject, though very useful, scattered through a large number of Papers. He thought if some member would take up the special subject of the effect of gradients on the working of railways, giving the results of experiments and facts within his own knowledge, certain rules might perhaps be established which would serve as a guide in deciding upon the gradients which, under different circumstances, would be most economical, where nature and circumstances gave an engineer a choice; but, as was justly said by Mr. Hawkshaw, very often it was necessary to take such gradients as Nature would allow, and with respect to which no choice was left.

February 9, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

The discussion upon the Paper, No. 1,202, "The Mauritius Railways—Midland Line," by Mr. Mosse, occupied the whole of the evening, to the exclusion of any other subject.

February 16, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,214.—"On the Lagoons and Marshes of certain parts of the Shores of the Mediterranean." By D. T. Ansted, M.A., F.R.S., For. Sec. G.S., F.R.G.S., &c., Honorary Member of the Institute of British Architects.

There are many important departments of Engineering in which considerations of Physical Geography and Geology enter largely and directly, and cannot safely be neglected. In subjects of this kind the observations of those who are not by profession Civil Engineers, but whose pursuits are in some measure analogous, have been too often and too directly appreciated by the Members of this Institution to admit of any doubt as to the reception of a Memoir treating on one of the most interesting among them. No apology need therefore be offered, for submitting the result of inquiries and observations made within the last three years, on the northern shores of the Mediterranean and the eastern coast of Corsica, with a view to determine the history of the lagoons, salt marshes, and swamps, that are there frequently accompanied by the worst forms of malaria, and of which there are so many examples. The Author is the more induced to direct attention to this subject, as he believes it to be certain, that a careful study of the mode in which the lagoons have been formed will in some cases suggest a simple method of sanitary improvement, and in others may point out in what way the marshy lands, now useless and poisonous, may be converted into cultivated fields, yielding luxuriant and profitable crops. He will endeavour to show that certain principles, based on the physical geography of these coasts, and dependent on their local geology, explain all the peculiarities of each separate case, and that a knowledge of these principles is indispensable for the effectual and economical removal of the evil, either by drainage, or by retaining the waters near a fixed level and uniformly salt. In justification for venturing to offer an opinion and advice, in a matter which may seem almost too exclusively engineering for a geologist to treat upon, it may be stated that the Author has from time to time had occasion to visit and examine professionally a number of instances of malarious coast connected with lagoons; that he is familiar, not only with those of the Mediterranean and of the Black Sea, but with others in the West Indies and in North America, and that he is acquainted

with the various engineering plans suggested, and the works carried on to improve them.

There is, perhaps, nowhere to be found a more instructive system of lagoons, salt marshes, and swamps, than that which has for its origin the Delta of the Rhone. This great river, which formerly emptied itself into the Mediterranean by a channel now called the Little Rhone, 35 miles west of its present embouchure, has been steadily advancing eastwards for a very long time, partly by natural causes, and partly in consequence of the construction of artificial works, consisting of embankments and canals, whose object has been to convey the flood-waters direct to the sea, and to leave large tracts of low flat land in a state fit for cultivation, free from the mischief of inundation. The river has now reached a limit towards the east, and a tongue of low land projects into the sea. Plates 13 and 14, which have been reduced from the recently published sheets of the French government maps, show the general form of the present delta and the principal channels by which the Rhone reaches the sea. The main delta is the Isle de la Camargue, between the main channel of the stream to the east, and the Petit Rhon or Little Rhone to the west. Many of the ancient channels are also marked.

The Rhone is a river exceedingly subject to floods, and it receives its large supply of water from three distinct sources. It drains the western flanks and spurs of the Dauphiny Alps by a number of considerable streams, and at length by the Durance, a torrent river conveying enormous quantities of detritus during flood seasons. It receives the Sâone after a long course from the north, and also the drainage of the eastern slopes of the Cevennes and the contiguous mountain ranges. Such a stream cannot fail to bring down a vast variety of detritus, much of which is deposited where the waters first enter the flat land. In this way is formed the delta. All the larger and coarser detritus is dropped at the upper part of the delta, but there remains a great overplus of sand and fine mud. Of this the less coarse part reaches the sea. On entering the low flat lands at the head of the delta, the rate of the stream diminishes, and there are a number of water channels. Originally these would shift each season, as they are known to do in similar cases where left to nature; but in the case of the Rhone, the channels are canalised, and the larger detritus entering them is made to fill up some hollow, and tend to the permanent elevation of the delta. The process of warping has been carried on from time immemorial, and is still pursued. In this way has been formed the large tract of the Camargue, the local name of the modern delta, parts of which, as has been said, are permanently reclaimed and cultivated, but a large portion consists of pools or sheets of shallow water nearly dry in summer. These pools are now filled with water entirely fresh or

slightly brackish, but originally they were occupied by salt water. Besides these pools, and between them and the sea, is a wide space occupied by salt water lagoons and salt marshes communicating still, more or less freely, with the sea.

The true delta of the Rhone is limited to the east by the gravel cliffs of the singular district called the Crau, and to the west by the western water-shed of the Vidourle, a river coming from the Cevennes, and only joining the Rhone at the very extremity of the delta. The total width thus limited is a little less than 40 miles. If a line be drawn from the mouth of the Vidourle to the east, passing the mediæval town of Aigues Mortes, almost all the country to the north side of this line will be found to be reclaimed and cultivated, while that to the south consists of lagoons, marshes, and sand-hills. Up to the thirteenth century of the Christian era, the sea appears to have reached this line in some places, as from Aigues Mortes Louis the IXth embarked, in 1249, to join the sixth crusade, and a galley of that period was found, in 1835, in the adjacent marshes, far within the present water-line of the dunes. This galley may now be seen in the Museum of the Louvre, in Paris.

Assuming, however, this ideal line as a kind of datum, the projecting accumulations of the Rhone detritus have for a very long time been deposited to the east of the Vidourle in two well-defined steps. That nearest the Vidourle and the ancient bed of the Rhone extends parallel to the datum, at a distance of about 7 miles to the south, and with a breadth of 23 miles; while the rest, nearest to the present mouth, extends double that distance, or 14 miles, with a breadth of about 17 miles. The extent of ground occupied by lagoons and marshes is, therefore, very much greater nearer the present than the ancient bed, and the delta is rapidly advancing in this part. Thus the tower of St. Louis, and some others built along the coast about six centuries ago, are now fully 2 miles within the delta. In other places, it is mentioned by Lyell (quoting French authorities) that the Tower of Tigneaux, erected in 1737, is now more than a mile distant from the shore, and that Psalmodi, an island in 815, is now 2 leagues from the shore. It is to be observed, that whilst the course of the Rhone has been for a long period receding towards the east, pseudo-deltas, extending far beyond the real delta, have been rapidly forming to the west.

Draining an unusually large proportion of mountain land, and therefore subject, in an unusual degree, to floods, the Rhone always conveys a large proportion of mud, but in freshets the quantity is enormous. Its stream also, as far as the head of the delta, is extremely rapid, and the delivery of water is large. Before the principal stream was embanked and confined it would, no doubt, shift from year to year, and in this way would fill up the breadth of the

delta; but now that this is prevented, the stream carries with it into the sea not only much water, but great quantities of sand and mud. Admiral Smyth records that, during the war with France at the beginning of this century, Sir Edward Pellew's ships anchored in the offing south-east of the Tour St. Louis, skimmed as much potable water as was wanted, "and at three-quarters of a mile from the shore the fresh run was about 3 feet deep." Although, therefore, the current of the river has been much diminished in rate in coming from Arles to St. Louis, over a dead level for 27 miles, there is still a considerable stream capable of carrying out to sea a large quantity of sand, silt, and mud.

It is only necessary to visit and travel over the Delta, and reach its sea limit, to understand clearly the mode of its formation. It would seem, however, that visits of this kind are very rare, as the Author can find no account of the Delta of the Rhone which gives the most distant idea of its present condition. Judging from the maps, it would seem to be a vast swamp, of which by far the largest part is covered with a sheet of water. In point of fact, however, a considerable part is cultivated; in other parts there are salt-works, here and there are tracts of sand covered with brushwood, juniper, and umbrella pine; while in the autumn it is perfectly easy to cross any part on horseback, and the water is nowhere more than about 3 feet in depth, with a hard bottom. A breed of almost wild cattle feeds on the pastures and brushwood, of which there is a large quantity.

The terminal line of the delta towards the sea consists of a long succession of sand-hills, a few feet above the mean level of the sea. Within this line, at a mean distance of about half a mile, though sometimes more and sometimes less, is another line nearly parallel to it, but more connected. This inner line is in places of considerable breadth, and admits of being fixed by vegetation. Within it there are generally pools of water, brackish at all times, but varying in saltness according to the season. These pools, as well as the outer lagoon, which is always salt, being entirely open to the sea, are all very shallow. The growth of the delta consists in the gradual closing up of the outer line of sand-dunes, so as to make it in time an almost continuous bank. During this time the innermost lagoon tends to fill up by warping, and the intervening one becomes less brackish as it is washed over, time after time, by fresh water. As soon as it becomes nearly complete, an outer line of detached hills begins to form, and thus each outer line in succession becomes an inner one, while each salt-water lagoon becomes first brackish, then fresh, and is ultimately filled up and reclaimed.

There can also be no serious doubt as to the origin of the sand-hills which form the first step in the enlargement of the delta. They are drifted by marine currents, and consist of part of the fine

detritus conveyed into the sea by the main stream. It is this distribution of the finer detritus on which the essential physical features of the delta depend. In the Gulf of Lyons the prevalent winds are south-east, and these produce a definite stream current sufficiently deep to convey sand, silt, and mud to a considerable distance. The deposit is kept up from the existing line of sand-hills by the drift that takes place seawards from time to time, when the inner lagoons become filled during and after freshets, and discharge their fresh water into the sea. The breadth of the interval appears to be a measure of this discharge.

In the various maps of the Delta of the Rhone, the Etang, or lagoon, of Valcares, is always a prominent feature. At the present time it covers about 25,000 acres, and is by far the largest sheet of water in the Delta. It is defended from the sea naturally, by an inner line of sand-hills, of the kind already described; but this is imperfect, and the water has remained brackish. It is now being reclaimed, and for this purpose a dyke or sea wall has been constructed which forms an effectual barrier. This barrier, however, is nothing more than a bank of loose sand, 6 feet above the mean level of the sea, obtained by cutting a trench on the inner side and throwing up the sand. This dyke, occasionally strengthened with a few fascines, is about 500 yards from the outer line of sand-hills. It is $16\frac{1}{2}$ miles long, and was completed almost entirely in the course of one winter, at a cost of £20,000. It was built in 1857. The Author rode along this dyke for a considerable distance, and only observed a few places where the rains had partly injured it. The bed of the lagoon within it is formed partly of fine silica sand and hard mud, and partly of a vast accumulation of shells of cockle (*cardium edule*). Fresh-water lymneæ and land snails are mixed in some places with the shells of cardium.

Except for the magnitude of the works, the difficulty of washing away the salt in the bed of the lagoons, and the smallness of the local population of the Camargue, there would seem to be no reason why the whole of the inner lagoons should not be reclaimed or utilized. Some, indeed, are already in process of reclamation, like the Etang of Valcares, while others are used as evaporating pans to obtain salt, of which a large quantity is here made. The district is unhealthy, being subject to ague and intermittent fever; but the malaria, though serious, is by no means so fatal as in some parts of the Mediterranean.

As a proof of the small amount of change in the surface of the Camargue, by either marine irruptions or floods of fresh water, it may be mentioned that while riding across some of the wildest parts near the sea, the Author observed, among some tamarisk bushes, the whitened skull of a horse, which his companion remembered to have seen in the same place more than sixteen years.

Fragments of Roman brick and pottery are found lying among the sand that forms the bed of the inner pools, mixed with the delicate shells of freshwater and land molluscs.

The works projected and partly executed. to drain the lagoons of the Rhone delta, are very primitive and inexpensive. Sand-dykes, such as that already described, a few brick and stone locks to control the influx and efflux of the water, a few canals, and some windmills to lift the water, make up the whole.

It has been mentioned that the natural termination of the Rhone delta is the water-shed of the river Vidourle, a comparatively small stream, draining a portion of the eastern flanks of the Cevennes, and entering the delta after crossing the gravel, which corresponds with the gravel of the Crau on the eastern side of the Camargue. But although the delta proper cannot be considered as reaching further than this, the deposits brought down by the river affect the coast for a distance of nearly 50 miles to Cape Agde, beyond the extremity of the Etang or lagoon of Thau. Again as far as Port Vendres, where the Pyrenees project into the Mediterranean, the coast is a line of sand banks, enclosing lagoons; but these probably have been formed chiefly by the detritus brought down by the Herault, the Orbe, and other streams crossing the plains of Languedoc. The exact origin of these extensions of sand deposits and the history of the lagoons connected with them is not yet clearly made out.

The Vidourle, though a small stream, during freshets brings down both water and mud in considerable quantities. It is now received, for the purpose of warping, into the Etang de Repousset, which is nearly filled up.

If the physical geography and geology of the country now drained by the Rhone, of the delta of that great stream, and of the Gulf of Lyons, be considered, with a view to make out the history of the remarkable string of lagoons, which extend without break from the extremity of the present delta to the Pyrenees, the task will be easier than might at first appear. It will also be admitted, that this study will point out the remedy, as far as there can be any, of the sanitary evil thus occasioned. The Author will venture, therefore, to give in a few words an outline of this chapter in the history of Europe.

The Rhone and the Saône occupy a great fissure between the very ancient but low chain of the Cevennes, continued northward under many names, and of the Western or Dauphiny Alps. Geologically speaking, the great east and west mountain axis, of which the Pyrenees and the Alps are the western extremity, was turned aside, as it were, by the still older north and south mountain axis, of which the Cevennes is the representative. Hence the broad and, at one time, deep bay, now filled with the detritus brought down

by the Rhone and its tributaries, and hence, also, the trending southwards of the Mediterranean shore beyond the present delta of the river. By a subsequent and comparatively recent elevation, accompanied by a line of volcanic eruption, the main direction of the Cevennes is retained as far as the Cape of Agde, which is a basaltic headland, and part of an almost unbroken line of volcanic ejections, extending from the Auvergne district into Spain. Thus the physical features of the district involve not only the line of the axis of the Cevennes already alluded to, but the line of basaltic eruption parallel to and at a little distance to the west of it. The former terminates in the mountain of Cette, the latter at the Cape of Agde. Beyond the Cape of Agde, as has been already pointed out, is the drainage of the plains of Languedoc, and beyond the bed of the Rhone, towards the east, there is no stream of any importance till arriving at the Var, a distance of 140 miles.

The distribution of the detritus of the Rhone is thus clearly traceable, and it is easy to see that the alluvial and other flat lands between the Rhone and the Cape of Agde can only be due to this source, with the exception of the wash of the hill sides, and the mud conveyed by the small stream of the Lez passing Montpellier, and draining a total area of 125 square miles. The drainage area of the Rhone is estimated at 37,000 square miles.[1]

The geological boundary of the deposits beyond the delta consists at first of the tertiary deposits, near Montpellier, then of the jurassic (Oxford clay) rocks of the Gardéole, and finally of the basaltic rocks continued from Central France towards the south, and seen at the Cape of Agde.

From the lighthouse of Aigues Mortes, behind which is the lagoon of Repousset, now being reclaimed by warping, the whole extension of the sand-banks, lagoons, and marshes, between the hills at some distance inland and the sea, is due to the Rhone detritus conveyed by marine currents. Plate 14 shows the position of these lagoons, their form and their relation to the drainage of the land. Taken in conjunction with Plate 13, which is to the same scale, the relation of the great delta of the Rhone, and these subordinate or pseudo-deltas, each containing its lagoon, will also be clearly recognised. The formation may have commenced long ago, but the present lagoons are not, in all probability, of very great geological antiquity. They form an almost unbroken succession, being only interrupted at long intervals by artificial embankments, and traversed by canals. Between the bed of the Vidourle and the first lagoon is a wide space of 1,800 acres,

[1] This represents the estimated drainage area of the stream according to old authorities. The French geographers have recently given as the drainage area of the Rhone system in France alone 45,884 square miles.

of which about 1,000 acres are marsh and the rest salt pans; the whole being slightly below the level of the Mediterranean. Beyond this space is the lagoon of Mauguio, which has a water area of about 8,000 acres in summer. It is nearly 7 miles long, and in most places from a mile and a quarter to a mile and a half across. Its greatest depth below the mean level of the sea is 4 feet 7 inches, its mean depth 3 feet 5 inches, and its waters in summer are about 8 inches below the lowest mean level of the Mediterranean. It communicates with the sea, at present, by a single artificial cut called the Grau de Pérols, which is the outlet also for the adjacent lagoon to the west. The sand-bank which separates it from the sea is a mile and a half wide at the eastern extremity, but it narrows rapidly to three-quarters of a mile, and is reduced to 500 or 600 yards near the adjacent lagoon. Towards the land side there are extensive marshes. All the villages and towns near it are very unhealthy, and the value of life in them is very small. Besides the rain that falls on its surface, the lagoon and marshes of Mauguio receive the drainage of an area of about 78 square miles, conveyed over land but little elevated, by a number of streams, the longest of which has a course of 13 miles. There is a line of watershed between the feeders of the Mauguio and those of the river Lez, separating naturally the lagoon of Mauguio from that of Pérols to the west. A tongue of higher land approaches within 350 yards of the sand-bank, which is here only about 700 yards wide. It is observable that the little town of Pérols, built on this tongue of land, is far less unhealthy than the adjacent towns to the east and west; but this is, no doubt, owing to its being more elevated above the plain. A slight elevation above the plain, where there is no tendency to drift the malaria to the level of the town, is generally a safeguard; but mere elevation above the sea, as in funnel-shaped valleys, or on the slopes of hills up which the air is obliged to pass in advancing inland from the sea, is no safeguard. The former case is illustrated in the valleys of Corsica, which will hereafter be referred to, the latter in the condition of the town of Cagliari, in Sardinia.

The lagoon of Pérols, including that of Grec and the marshes immediately around, occupies in all about 3,300 acres. Of this the actual lagoon of Pérols occupies 1,925 acres, and that of Grec 500 acres, the two being only separated by an artificial canal: the remaining part of the larger area to the north, about 475 acres, consists of marsh-land, and of the smaller area to the south, about 500 acres, of salt marshes. The mean depth of water is only 14 inches, and the maximum depth 33 inches below the summer water level, which is 7 inches below the mean level of the Mediterranean. The lagoon of Grec is shallower than that of Pérols, its maximum depth in summer being only 20 inches below

the Mediterranean. The marshes round the lagoon of Pérols are 10 inches above the summer water level. There is very little drainage into these lagoons from the land.

Essentially the three lagoons of Mauguio, Pérols and Grec form but one, with only one natural outlet to the sea; but the line of sand-bank is not sufficiently complete to exclude the sea during storms. This natural outlet is towards the furthest extremity, measuring from the Rhone delta, which is the source of the drifted material that has enclosed the lagoons. The conditions are those least favourable for sanitary requirements, as the water in summer is more or less salt and very warm. It is also liable to be rendered almost fresh during the rainy season, by the influx of rain-water brought into it by torrents. After long evaporation the water becomes exceedingly salt in dry weather. The large area of marsh-lands, nearly 5,500 acres, at present left around the lagoons almost without drainage, fully accounts for the unhealthy state of the district. It is proposed to drain effectually all the marshes, and a large portion of the lagoons, so that in place of the present unhealthy waste, there will be about 8,800 acres of valuable cultivable lands, and a permanent lake of 6,750 acres in open and free communication with the sea. The estimated cost of these works is £53,400, and they would need a permanent expenditure of £2,560 per annum for keeping up the works. It is proposed to use wind-mills to lift the water.

The river Lez enters the sea by an artificial channel, separating the lagoon of Pérols from that which next succeeds to the west. The whole system of lagoons and marshes between the Vidourle and the Lez may be traced to the fact, that the natural discharge of the land-waters into the sea being intermittent, long intervals elapsing between any sweeping currents, the sand and mud drifted from the mouth of the Rhone have been enabled to form sand-banks, which the occasional torrents have failed to remove. Thus have been established numerous pools and lagoons, into which at first the sea could enter freely, and which could readily discharge their surplus waters; but which in time have become closed, leaving only one imperfect outlet often choked up. Between the Vidourle and the Lez, the total area of the land draining into the lagoons is about 125 square miles. The Lez, although not draining a large area, has to drain a multitude of small valleys, and thus, though generally small, it is liable to sudden and heavy floods. It is formed by two principal branches uniting close to the outlet. They are called respectively the Lez and the Masson. Of each the total length of course is about 25 miles. The total drainage area is, as already stated, 125 square miles. In a climate where the rain-fall is at all equally distributed, such a stream could hardly be regarded as important; but in this part of the south of France,

owing to a combination of causes, the showers are sometimes exceedingly heavy. As an example of this, it may be mentioned that, on one occasion, in the month of October, 1868, the Author measured a rainfall of 7 inches within twenty-four hours, almost the whole fall being, in fact, within fifteen hours.[1] The Lez may thus now and then be subject to enormous floods of water, conveying large quantities of detritus into the sea. All this must be distributed by marine currents; but in the intervals between two rainy seasons several months may elapse without any rain, and the amount of mud and sand drifted along the coast is amply sufficient to close the channel for the time. These are conditions that can hardly fail to result in the formation of a lagoon, and the lagoons of Mauguio and Pérols, near the mouth of the Lez, are examples which admirably illustrate this view. It is probable that as the Lez is now canalised, there will be little difficulty in carrying into execution the proposed works, and restoring the healthiness of the surrounding country, by draining the marshes, and opening the lagoon of Mauguio into permanent communication with the sea.

Beyond the Lez to the west are three connected lagoons, before reaching the great lagoon of Thau, into which they open. The total length of coast enclosing these three lakes is 13½ miles, and the total area of water 11,280 acres. They are called respectively the Etangs of Villeneuve, Vic, and Frontignan, the passage from the latter to the lagoon of Thau being called 'les Eaux Blanches.' All these waters are very shallow, the deepest parts not exceeding 40 inches below the Mediterranean. Of the different sheets of water, that nearest the Lez (Villeneuve) occupies about 3,000 acres; the next (Vic) about 4,820 acres, including the marshes; the next (Frontignan) 2,730 acres, and the Eaux Blanches about 730 acres.

These lagoons receive the drainage of a tract of land amounting to about 33 square miles, between the range of hills called the Gardéole and the sea. This range comes to an end in a kind of peninsula, stretching into the lagoon of Thau as far as Balaruc, where are some celebrated hot springs. The mountain of Cette is of the same formation geologically, and is a detached hill of the same line of elevation. For the reasons already assigned, this area of drainage, although small, is fully sufficient to justify the group of lagoons between the plains and the present coast line.

The lagoon of Thau is a sheet of salt water 11½ miles long, and in most parts more than 3 miles broad; its total water area being about 20,000 acres. It has no natural outlet to the sea, except by a narrow neck, extending beyond the extreme southern extremity, but there is an artificial channel kept open at Cette. The shores

[1] This was at Villeneuvette, near Clermont, in the valley of the Hérault.

are not remarkably unhealthy, owing to the fact that the water is generally kept at the same level, and the degree of saltness is almost uniform throughout at all seasons. It is not surrounded by marshes. Beyond the lagoon is a coast line of about $3\frac{1}{2}$ miles to the Cape of Agde, within which are about 300 acres of pond and marsh. The headland, on which is the lighthouse of Agde, is volcanic in its origin, and is part of the extensive tract of basaltic rock, extending southwards from the Auvergne country and the Vivarais. The eastern side of the high ground, thus determined, drains into the lagoon of Thau. The total drainage area supplying it with water is nearly 120 square miles, chiefly consisting of a strip of land near the lagoon about 6 miles in width, but part of it rising into considerable hills, and extending some distance to the east of the lagoon.

It must not be lost sight of, that these large sheets of shallow water, surrounded by marsh, are liable to a sensible increase in their volume merely by the quantity of rain that falls on their surface during the heavy rains that sometimes occur. Thus, in the case of a rain like that in the month of October last, the mere surface fall, without any addition from drainage, would add one-fourth to the volume of water contained in some of the basins. Unless, therefore, the means for removing surplus water are unusually complete, the result could not fail to be very troublesome, for such showers run off the land rapidly, and are difficult to guide. The drainage of a system of lagoons of the kind now under consideration, if carried on without recognition of the history of its formation and its mode of growth, as well as of the conditions to which it is now subject, can hardly be expected to be a successful operation; and it is notorious that, in countries where the rainfall is much smaller, and the maximum fall in twenty-four hours not half that of the plains of Languedoc, very extensive works have failed, owing to the impossibility of removing the incoming torrents, after heavy rain, with sufficient rapidity.

The works already carried on in the district appear to be to a great extent in a right direction. They consist of a series of canals, connected with open cuts, the water to be lifted at certain places by windmills. These are intended to drain a part of the lagoons and the whole of the marshes. The rest of the lagoons will be put in free communication with the sea. The artificial channels made for the passage of the waters of the Lez into the sea, and those for introducing the sea into some of the lagoons at will, are already in operation. They are constructed with a view to permanence, and are very efficacious.[1] There seems no reason why, if the principal

[1] These are executed according to the plans and under the superintendence of M. Régy, the Chief Engineer of the Ponts et Chaussées, resident at Montpellier. This gentleman's plans for the whole drainage of the system of lagoons are prepared; and the printed statement appended to them (for a copy of which the Author is indebted

streams can be made to convey their waters direct to the sea when this is required, or to deposit their detritus in still water before they reach the sea, when warping is necessary, there should not be a permanent improvement in the general condition of the coast. The work, however, is on a very large scale and needs to be carried through with caution. The annexed tabular statement will give some idea of its nature in the district now under consideration. It refers to the whole of the lagoon and marsh lands of the delta of the Rhone, and the coast to the west, affected by the deposits brought down by the Rhone, and distributed by the currents of the Gulf of Lyons:—

Description of the Surface.	Length of Coast in Miles.	Total Area (in Acres) of Lagoon and Marsh.	Approximate Area in Square Miles, draining into the Section.
Delta of the Rhone between the Crau and the ancient bed of the Vidourle	40[1]	50,000[2]	37,000[3]
Ponds and marshes between the Vidourle and the canal of Lunel	$\frac{3}{4}$	1,800	40
Basin of Mauguio between the canal and the extremity of the lagoon of Mauguio, chiefly marsh land	$\frac{3}{4}$	2,700	80
Lagoon of Maugnio	7	8,080	
Lagoon of Pérols, from the lagoon of Mauguio to the river Lez, including the Etang de Grec, being the part of the Lagoon of Pérols south of the Canal des Etangs	$2\frac{1}{4}$	3,340	125
Lagoon of Villeneuve, or Arnel between the river Lez and the lagoon of Vic, and the lagoon of Magnelonne or Prevost, being the part to the south of the canal	$3\frac{1}{2}$	3,000	
Lagoon of Vic, and various basins and salt-marshes between it and the lagoon of Frontignan	$3\frac{1}{2}$	4,820	
Lagoon of Frontignan, and salt-marshes, &c., adjoining	$3\frac{1}{2}$	2,730	
Basin of Eaux Blanches, between the lagoons of Frontignan and Thau	$2\frac{1}{2}$	730	
Lagoon of Thau (including lagoon of Eaux Blanches), to the outlet at the south end .	$11\frac{1}{2}$	20,000	120
Pools and marshes between the Grau de Thau and Cap d'Agde	$3\frac{1}{2}$	300	..
	$78\frac{3}{4}$	47,500	365

indebted to the kindness of M. Régy,) has supplied many of the details in this account of the lagoons. Plate 14, Fig. 2, has been prepared from a rough tracing which the Author was permitted to take from M. Régy's unpublished plan. *Vide* Ann. des Ponts et Chaussées, 4e série, Tome V. p. 209.

[1] This is not the total length of coast line, which is nearly 60 miles, but the width of the delta in longitude. The miles are British statute miles throughout.

[2] The total area of the "Ile de la Camargue," according to a Report by M. Garella in 1829, is 73,000 hectares, or about 180,000 acres. The part now covered with water is roughly estimated as above.

[3] *Vide* note, p. 293.

After passing the Cape of Agde, there are on the coast to the south a number of small lagoons and several streams entering the Mediterranean. There is, however, no system of lagoons resembling that just described. The reason is to be found in the nature of the streams, which are sufficiently powerful to preserve an open communication all the year round, and to prevent the formation of sand-banks. These banks, by enclosing a part of the winter flow, soon form a permanent lagoon in or near the mouth of the stream. The rivers are sufficiently near each other to prevent any considerable amount of drainage area entering the sea between them.

The Author desires next to direct attention to another group of lagoons accompanied by malaria; occupying a somewhat different position, as not being connected with the delta of a first-class river, but capable of being explained without much difficulty by reference to the geology, or rather to the physical geography, of the district. He refers to the lagoons on the eastern side of the island of Corsica, and chiefly to the lagoon of Biguglia, the largest of all, and that whose drainage would more than anything else improve the sanitary condition of the island. The map, Plate 15, taken from the old French government map, as being the best authority at present available, represents the coast as it was half a century ago. It has since undergone some change.

Corsica has a backbone of mountains, which range nearer the western than the eastern side. Spurs from these mountains approach the eastern shore, but leave a belt of plains about 60 miles long and 3 miles or 4 miles wide. Between these spurs rivers come down and traverse the plains to enter the sea. Of such streams there are three of some importance, and a large number which are rather torrents than rivers, bringing down water only during the rainy season, and either dry, or nearly so, during summer. The Golo is one of the principal streams, and that farthest to the north: the Tavignano is of about the same magnitude, and the Orbo is smaller. There are systems of lagoons dependent on each. Between these principal streams are the beds of several torrents, always dry in summer.

The Golo enters the Mediterranean about 15 miles south of the town of Bastia, after a course of 50 miles, draining about 320 square miles of country. It brings into the plains, and carries into the sea, a large quantity of detritus, which is distributed by the prevailing currents along the coast to the north. The whole of the plains near the present embouchure are composed of gravel and detritus brought down at some former time, now occupying a plain nearly 4 square miles in extent, between the river and the commencement of the great lagoon which next succeeds. This lagoon extends for about $7\frac{3}{4}$ miles in length, parallel to the coast,

with a maximum breadth of about 2,000 yards, but an average breadth of about 1,000 yards for a distance of 6 miles. Beyond this is a passage or canal 1½ mile long, and about 80 yards wide, open to the sea at its farthest extremity to the north, the communication being kept open artificially. The total water area is about 4,750 acres. The depth of water is very small. The maximum depth in the open lagoon is 4 feet 6 inches, but at one place in the canal it is 10 feet. The mean depth is about 33½ inches.

This lagoon is at present shut off from the sea by a sand-bank, 900 yards wide at the southern extremity, near the river Golo, gradually diminishing to 400 yards at the other end. The height is in most parts about 8 feet or 9 feet above the Mediterranean, but there are two low parts over which, during great storms, the waves can at present wash. These are about 300 yards wide. The level of the water in the lagoon is generally a little below that of the Mediterranean, but after heavy rains it is higher, and during summer much lower. The water in summer is very brackish, but during winter and spring it is nearly fresh everywhere. It passes, indeed, at different seasons through almost all possible stages of saltness, besides varying in depth to an extent amounting to almost half the mean depth.

The drainage area supplying water to the lagoon is large. It amounts in all to about 70 square miles, being at the rate of 68 acres of lagoon for each square mile of drainage area. This proportion is unfavourable when compared with the whole system of lagoons on the coast of Languedoc, already described, where there are about 130 acres to the square mile. Deducting, however, the lagoon of Thau, where the proportion is exceptionally large (167 acres to the square mile), the general average of the rest is about 100 acres to the square mile, and this agrees nearly with the cases of the separate lagoons.

It is evident that the difficulty or facility of draining and keeping dry a lagoon must depend partly on the proportion of drainage area to the area to be drained, and partly on the distribution and amount of the rainfall. It is hardly requisite to point out the necessity of considering both these matters before attempting to calculate the cost of draining operations, or, indeed, the possibility, in an economic sense, of executing them. It is clear that, so far as the proportion of areas is concerned, the drainage of the lagoon of Biguglia would render the work much more troublesome and dangerous than that of any of the lagoons of the Rhone delta. Before, however, considering how far the meteorological conditions might modify the case, it is advisable to inquire into the method in which the drainage is distributed, and whether, by a study of the physical features of the district, the matter may not admit of great simplification.

The whole drainage area of the Biguglia district may be con-

sidered as distributed into three parts, which will be best understood by referring to the map, Plate 15, but which may be thus described. By far the largest part is that nearest the Golo, and extending thence to the water-shed of the small river Bevinco, the largest of the various streams and torrents that carry water into the lagoon. The Bevinco is a permanent stream of some importance, having a length of course of 12 miles, and draining a district of about 30 square miles. Before the sand-bank now enclosing the lagoon of Biguglia had reached the point opposite the Bevinco, this stream must have entered the sea by a passage now choked up, but across which the waves occasionally break in stormy weather. There can be no doubt that, until the closing up of this channel, the sea entered the part of the lagoon to the south, and preserved it permanently salt. Now, however, that the waters of this stream are thrown into the lagoon, they accumulate in the wide expanse to the south, and can only be discharged slowly by the outlet artificially kept open more than a mile to the north. There is a small drainage area of about 7 square miles draining into the part of the lagoon to the north of the Bevinco, and into the channel beyond, and this forms the third division of the lagoon. The whole drainage area is, therefore, thus distributed:—

—	Area in Acres.	Drainage area in Square Miles.	Proportion of Acres of Lagoon to Square Miles of Drainage
1. Southern and principal part	4,000	30	1 to 130
2. River Bevinco	..	32	..
3. Northern extremity and channel	350	7	1 to 50

Of these the former part is the old lagoon, which had been gradually increasing in length, diminishing, as usual, in breadth, from the time when the delta of the Golo first began to be distributed. The third part was probably a small lagoon, added when the waters of the Bevinco could no longer escape to the sea. The complete and modern lagoon of Biguglia dates only from the time when the channel of the Bevinco was closed.

It is evident that the enclosure of the waters of the Bevinco, which, till a comparatively recent period, entered the sea at the point where there is now a low break in the sand-bank opposite the mouth of the stream, has not only been the cause of the completion of the lagoon of Biguglia in its present form, but also of the extreme unhealthiness of the surrounding country. In a report recently submitted to the "Ponts et Chaussées," by M. Duponchel, Ingenieur Ordinaire, on the subject of the Etang, it is pointed out that the average mortality for the ten years, 1857 to

1866, for five communes near Bastia, not under the influence of the lagoon, was 19 per thousand, whereas, in four communes near the lagoon, it amounted to 39 per thousand, and close to the spot was 44¼ per thousand. It is a case extremely similar to that of the Lez, on the coast of Languedoc, which, however, being a larger stream, and draining three times the area, has been able to keep a clear channel, and requires but little assistance for this purpose. The Bevinco diminishes to a mere thread of water during extreme dry weather, and at this time the encroachments of the sand drifting from the Golo are sufficient to close it entirely. In autumn and winter the rains produce torrents which, since the closing of the channel, have been spread over the whole lagoon of Biguglia, instead of making their way direct to the sea.

Under these circumstances the first measure of improvement must be a restoration of the Bevinco to its former channel, a removal of all possibility of its waters entering the Biguglia, and thus the placing of the main lagoon in a position entirely analogous to that of the various lagoons on the coast of Languedoc. It cannot be doubted that in this manner the actual drainage of the Biguglia, which would probably be necessary to render the coast healthy, is removed from the class of works practically impossible, which has been up to this time the opinion of the French Engineers. In the report above referred to, dated August, 1869, it is proposed for the first time to canalize the Bevinco, as suggested by the Author in 1867. By preventing the influx of all the waters now entering the lagoon from the torrents that at present discharge into it, and conducting these streams by a system of catchwater drains, partly into the Golo and partly into the Bevinco, the remaining surface drainage, and the rain falling on the lagoon, would be easily kept under control; and the lake once drained, the noxious exhalations and malaria, to which it is now subjected, would be carried away by vegetation, and by a succession of forcing crops.

The history of the coast of Corsica illustrates very clearly the view here taken. Up to the middle of the seventeenth century the coast was at least moderately healthy, and there was then a town of some importance (Mariana), on the north side of the Golo, on the shores of the lagoon. The lagoon was then no doubt open entirely to the sea. This town of Mariana was the seat of the bishopric of an extensive and rich diocese. Its ruins remain, but the neighbourhood is not now habitable in summer. The closing of the lagoon and the shutting in of the waters of the Bevinco were probably rapid, and the consequence has been the retention, in the lagoon, of the large quantities of decaying organic matter which is brought in by the Bevinco and the various torrents. The total absence of the circulation of the water during summer,

when the heat and evaporation are greatest, and the high temperature of so large a sheet of very shallow water, produce a rapid growth of confervoid vegetation on the water, and this is drifted in enormous sheets to the inner shore, where it accumulates and rots. The smell arising from the lake is then very offensive, and a mist hovers over the surface. The smell and miasma are drifted up the valleys by the prevalent south-easterly winds, and thus not only the plains adjacent to the lagoons, but the greater part of the eastern side of the island becomes poisoned. In all the valleys the villages are unhealthy, and the town of Bastia itself suffers severely. The death-rate of the communes north of Bastia, entirely removed from the influence of the lagoon, is only from $16\frac{3}{4}$ to 18 per thousand. In the town of Bastia it is nearly 22.

Unfortunately for Corsica the conditions of the Golo are repeated, though in a less mischievous manner, at the mouth of the Tavignano, the Orbo, and the other principal streams. Near the Tavignano is the lagoon of Diana, now closed and unhealthy, but formerly open and healthy. Occupying precisely the same position between the lagoon and the river, as is the case with the mediæval town of Mariana, there was, in the time of the Roman occupation of Corsica, another town, Aleria, of which, also, ruins exist, but which has long ceased to be habitable. The lagoon of Diana is, however, deeper than that of the Biguglia, and requires different treatment. Beyond the Tavignano, and between that stream and the Orbo, is another large lagoon, the Urbino, besides smaller sheets of water, and still more to the south is the lagoon of Palo. The succession of so many lagoons and marshes on the 60 miles of coast that bound the eastern plains of Corsica, have checked all progress, and rendered these plains barren wastes, although they are marvellously rich in soil, and formerly yielded enormous crops. To restore the coast to its ancient condition of health, would probably render the valleys perfectly healthy, and enable the population of Corsica to double itself in a short time. The measures required for this improvement must, it is believed, have strict reference to the physical conditions that have caused the malaria.

The statistics of rainfall on the Corsican coast are not satisfactory. The observations range over only a short period, and though detailed they refer only to one station in the town of Bastia. They appear to prove, however, that the climate is, as might have been expected, more insular than that of the coast of Languedoc, the total amount of rainfall being distributed over a longer period of days, and the showers being less heavy. During the three years, 1861-1863, the mean total fall was about 24 inches, of which 10 inches fell in October and November, the rest being distributed over the winter and spring months. The maximum fall in twenty-four hours was a little more than 2 inches; the maximum weekly fall nearly 4 inches; the maximum monthly fall 12 inches. In

the report already referred to, it is stated that a heavier rainfall than seven centimètres ($2\frac{3}{4}$ inches) in twenty-four hours, has not been known even in exceptional storms. A large proportion of the heavier showers would naturally reach the lagoon, for the distance is small, and the ground falls with tolerable rapidity: but the hill sides are everywhere covered with vegetation. The drainage of the mountains is, of course, discharged by the large rivers.

The rainfall statistics of the neighbourhood of Montpellier, and the coast of the Mediterranean near the delta of the Rhone, prove that the records of a few years not only fail to give a fair average, but that even a good average, if obtained, is of little value by itself, in inquiries that have any practical bearing. Throughout this part of Europe, the seasons recur in cycles of many years, and the rainfall, after being moderate and regular for a number of successive years, changes altogether its character, becoming for several years not only more excessive, but characterized by storms of tropical magnitude and rapidity. Allusion has already been made to a shower or succession of showers, during the month of October last, in this district, when in a period of twenty-four hours as much as 7 inches of rain fell. Such showers, though not common, are characteristic of the climate in this respect, and they are important as introducing elements of difficulty in drainage works which it would be unwise to neglect.

Over the delta of the Rhone itself, the rainfall appears to be about one-fifth less than the fall at and near Montpellier. For fourteen years before 1868, there had been a succession of wet seasons, the mean annual fall amounting to 40 inches; but previously there had been dry seasons, when the quantity of rain was much less. After the dry summer of 1868, a very heavy rain, which had taken place within a fortnight, had not produced much effect on the waters of the lagoon of Valcares, though its influence was seen in the countless swarms of gnats darkening the air during the day throughout the delta.

The following Table of the rain statistics of the town of Montpellier are interesting, but must not be regarded as sufficient to justify any general conclusions from the average:—

——	Jan. to March.	April to June.	July to Sept.	October to Dec.	Total.
	Inches.	Inches.	Inches.	Inches.	Inches.
1857	11·81	5·16	16·34	15·75	49·06
1858	9·68	2·95	3·38	9·37	25·38
1859	4·96	6·69	1·50	6 77	19·92
1860	10·43	8·20	6·89	14·05	39·57
1861	12·64	7·40	3·50	9·57	33·11
1862	8·23	5·27	11·53	26·11	51·14
1863	5·43	5·59	7·83	14 72	33·57
1864	8·74	2·28	1·50	28·31	40·83
Means	9·00	5 44	6·56	15·58	36·58

At Carcassonne, the mean of the ten years 1849--1858 was 29·88 inches: the position of this town explains the difference. The following details of the rainfall in Bastia for the three years of corresponding observation are interesting:—

——	Jan. to March.	April to June.	July to Sept.	October to Dec.	Total.
	Inches.	Inches.	Inches.	Inches.	Inches.
1861	..	..	..	5·67	20·12
1862	6·53	4·41	2·95	15·83	29·72
1863	..	..	..	12·21	22·84

They indicate a much smaller rainfall generally, but a considerably larger proportion during the winter months. This appears to correspond with general experience.

Besides the marshes connected with, and almost forming part of the lagoons, and the lagoons directly derived from river deltas, there are others in the extended plains of Languedoc, on the coast of Provence, and on the islands of the western Mediterranean, off the coast of Spain. There are also extensive groups of lagoons at the head of the Adriatic, connected with the delta of the Po, and others in the eastern Mediterranean, and on the western shores of the Black Sea near the mouths of the Danube. In each case there is something special, and each must be dealt with on its own merits, and after a careful consideration of the physical geography of the district. But a large proportion of the lagoons must certainly be referred to the cause pointed out, the drifting of transported material by marine currents along lines of coast, where the natural drainage of the land has not the strength to sweep a clear channel through the silt accumulating in front of it. Under such circumstances a careful study of the physical conditions of the surrounding country, and a knowledge of the history of the formation of the lagoon, as derived from observation, should precede any attempt to remedy the evil attendant on malaria, if that has already been prevalent. This is the case whatever be the proposed remedy, whether by draining the lagoons and reclaiming the land if that be practicable, or if not, by opening the lagoons to the sea by permanent canals, and locks capable of being kept clear of obstruction from the constantly advancing sands. In observations of this kind, a knowledge of the general physical geography and meteorology of the district seems to be absolutely indispensable, and an acquaintance with the local geology extremely useful.

The practical bearings of the facts and inferences submitted in this communication may be thus briefly summarised:—

First. That the malarious lagoons and marshes, of which there are so many examples on various shores, are the result of the

interception of waters coming off small tracts of land, or of small and torrential streams, by banks of drifted sand and mud, proceeding from larger rivers, carrying out to some distance a large quantity of detritus which is distributed by marine currents.

Secondly. That a study of the existing physical geography of each district affected by malaria, combined with a knowledge of its geology, is sufficient to explain the conditions, and to determine the history of the operations that have terminated in the formation of the malarious marshes and lagoons.

Thirdly. That the removal of malaria, whether to be effected by complete drainage or by partial drainage, accompanied by the keeping certain lagoons in free communication with the sea, can only be hoped for by engineering operations, based on the special history of the case under consideration, as determined by a knowledge of the physical geography and geology of the district.

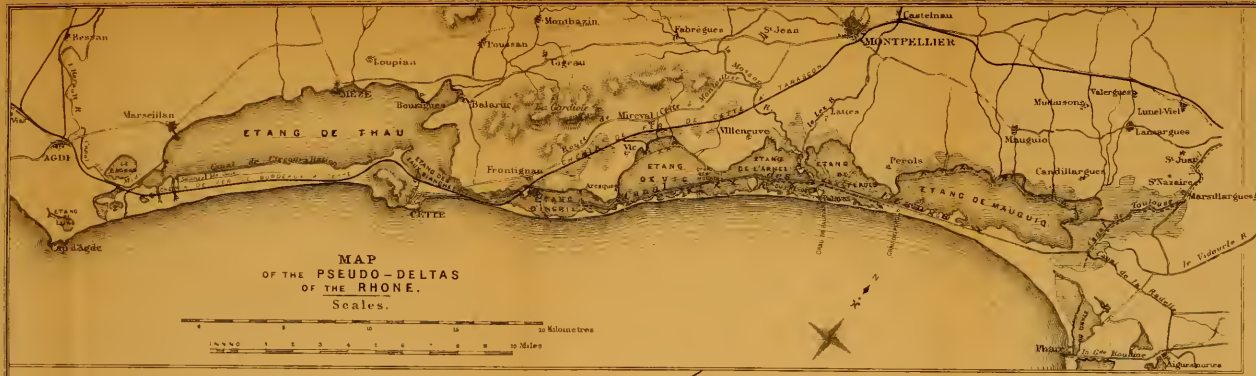
Fourthly. That, in certain cases where small torrential streams have been kept back from the sea by the rapid accumulation of drifted sand, the drainage of the marshes and lagoons may be rendered comparatively easy by keeping open a permanent channel for such streams.

Fifthly. That the principle of breaking up the large drainage areas which supply water to the lagoons into smaller areas, each of which admits of separate treatment, being suggested by the history of lagoons generally, is the principle which should be adopted in all cases where sanitary improvement is called for, and will generally be found advantageous in an economic sense.

The communication is accompanied by a series of diagrams, from which Plates 13, 14, and 15 have been compiled.

MAP OF THE DELTAS OF THE RHONE,
INCLUDING THE ISLANDS OF THE CAMARGUE AND THE CRAU.

Gallargues
Beauvoisin
Vauvert
Almargues
Le Cailar
LUNEL
Marsillargues
St Laurent
Aigues Mortes
ETANG DE SCAMANDRE OU DES ISCLES
Marais du Cros
Marais de la Fosse
Marais de la Grand Mar
Marais de la Souteyrenne
Rhône
Petit Rhône
Canal de la Radelle
Canal des Launes
Canal des Saintes Maries
ETANG DE LA MATTE
ETANG DE LA VILLE
ETANG DU COMMUN
ETANG DU ROI
ETANG DU GALUS
ETANG DU VALCARES
ETANG DE MALGROU
ETANG DU LIOU
ETANG DU VAUNAGET
ETANG DE LA DARE
Route d'Aigues mortes aux Stes Maries
Route de Beaucaire aux Stes Maries
Stes Maries
Grau d'Orgon
GOLFE DE BEAUDUC
Scales
ARLES
Fourques
St Gilles
Petit Rhône de Lunel à Arles
Chemin de fer
Canal de la Crau
Canal de Craponne
Canal de Navigation du Grand Rhône
Canal de la Vallée des Baux
Canal de la Vallée des Alpines
Canal de la Méditerranée
LA CRAU SUR DURANCE
LA CRAU
CAMARGUE
GRAND PLAN DU BOURG
ILE DU PLAN DU BOURG
Grand Rhône
Bras de fer
Bras de la Gachette
Bras de la Roubine
Marais de Pont de Rousty
Marais de Sabatier
Marais de la Grand Mar
Marais de Capeau de Paluette
Marais de Trébon
Marais de Fourcon
Marais de Honc
Marais de Meyranne
Marais de Chanoines
Marais de Rouelles
ETANG DE CAPEAU
ETANG DE BOLMON
ETANG DE BERRE
Aureille
Eyguières
Lamanon
Salon
Mouriès
Craponne
Canal des Alpines
Canal de Branche des Alpines
Canal de Craponne
Canal de Vallée des Baux
Canal de Vallée des Alpines
Canal de Navigation
Canal de Marseille
Canal de Provence
Canal de Boisgelin
Canal de Pourcieux
Canal de Fontvieille
Canal de Fontvieille à Arles
Canal de Fontvieille à Tarascon
Canal de Fontvieille à Boisgelin
Canal de Fontvieille à Pourcieux
Canal de Fontvieille à Provence
Canal de Fontvieille à Marseille
Canal de Fontvieille à Navigation
Canal de Fontvieille à Vallée des Alpines
Canal de Fontvieille à Vallée des Baux
Canal de Fontvieille à Craponne
Canal de Fontvieille à Branche des Alpines
Canal de Fontvieille à Salon
Canal de Fontvieille à Lamanon
Canal de Fontvieille à Eyguières
Canal de Fontvieille à Aureille
Canal de Fontvieille à Mouriès



MAP
OF THE PSEUDO-DELTAS
OF THE RHONE.
Scales.

10 Kilometres
10 Miles

PLAN OF WORKS PROJECTED
FOR THE DRAINAGE OF THE LAGOONS.

REFERENCE TO PLAN.

- Salines
- Marshes
- Dykes proposed
- Cuts proposed
- Grans or open Channels
- Windmills
- Limits of Basins
- Limits of Sections
- Depth of Water 1 metre, 2, 3

MAP OF PART OF THE EASTERN COAST OF CORSICA.

PLATE 15

PLAN OF THE LAGOON OF BIGUGLIA, CORSICA.

ILLUSTRATING THE PROPOSED DRAINAGE SYSTEM

Professor ANSTED remarked, that the results recorded in the Paper were derived from personal observation of works suggested and partly carried out by French engineers; and he had endeavoured to illustrate them in such a way as to direct attention particularly to those geological and geographical features which seemed to be of importance. He was aware of other somewhat similar works that had been carried out, with more or less success, on the shores of the Mediterranean, but his remarks had been strictly confined to facts within his own observation. It should be remembered that he was not a professional engineer; but his object for many years had been to bring the sciences of geology and physical geography to bear upon questions of practical engineering.

Mr. BATEMAN said, he was carrying out some works of reclamation and irrigation in the delta of the River Ebro, and at Majorca, and could bear testimony to the general accuracy of Professor Ansted's descriptions, both as to the present character and nature of the lagoons, and as to the causes which had produced them. The deltas of the rivers consisted generally of fine particles brought down from the districts above and deposited at the mouths. These lands were easily capable of being reclaimed, and of being converted into valuable soil for cultivation. The lagoons and the adjoining lands, on being shut out from the sea, produced a rank growth of vegetation, mixed with detritus brought down by the streams or by rain. The land was valuable for agricultural purposes, when properly drained and irrigated, but the quality varied much, and each case required special consideration. Professor Ansted had alluded to the vast lagoons near Narbonne, which lay to the east of Perpignan. These water-covered lands would no doubt before long call for the labours of the engineer; and in Italy, on the shores of the Adriatic, and on the shores of the Mediterranean, there was a great extent of marsh land and shallow lagoons, requiring similar treatment, which was likely to afford a large amount of engineering and professional employment.

Professor ANSTED said, he had been asked to supplement the Paper by a few remarks on the engineering details of the works carried out on the shores of the Mediterranean. These were of interest to those who took general views of engineering operations of this kind, and were valuable in a sanitary point of view, though perhaps not directly profitable. With regard to the particular districts to which he had drawn attention, he might remark that the operations on the shores of the Mediterranean were different in some respects from those of the same general kind usually carried out on the British coasts, and on a larger scale in Holland, and at the mouth of the Rhine. The shores of the North Sea were liable in an unusual degree to tidal influence, and were also subject to the action of an ocean advancing along a channel narrowing by degrees,

and causing, from time to time, a considerable rise in the general water level, which produced a marked effect upon all engineering operations. At the head of the great bays in the Mediterranean—in the Gulf of Lyons on the one side, and at the head of the Adriatic on the other—there was scarcely any tide, and only inconsiderable stream currents, but there were winds blowing sometimes steadily from one quarter, and producing occasionally a rise in the height of the water; there was however little difference in the operations of Nature on the shores of the North Sea and on the shores of the Mediterranean.

With these preliminary observations he would now direct attention to the nature of the works existing and projected. These did not involve the great outlay usual on the coasts of England; still less the gigantic operations carried on in Holland. But though smaller and less expensive, they were hardly less necessary or less efficacious. They were also profitable in a degree, and advantageous when they modified the exceedingly unhealthy condition of some of those coasts, and rendered large tracts of land habitable and healthy.

There were two kinds of works to be considered. One included those having reference to the river deltas, and more especially the delta of the Rhone; the other related to what he had called the pseudo-deltas—that great expanse of mud and sand, but chiefly sand, which was carried out beyond the true delta, producing an expanse of flat, low, sandy lands, often very unhealthy, and generally connected with extensive marshes, but which he believed could be rendered healthy by simple operations. In that part of the delta which extended from the present mouth of the lower Rhone to the extreme point of the Rhone delta to the west, there was a large tract of land of which a considerable portion was under shallow water, and this had long been the subject of engineering works of a simple kind, consisting merely of lines of dykes constructed of sand, and a corresponding ditch from which the sand was obtained. The only important consideration in connection with this operation was, that it should be executed within a few hundred yards of the sea. Close to the sea there was often a natural line of sand-hills, from 3 feet to 6 feet above the mean sea level, which mean was only liable to be changed to the extent of 12 inches or 14 inches, by the ordinary influence of tide. Occasionally, however, owing to a long continuance of south-east winds, the water rose considerably at the head of the Gulf of Lyons, being pushed up by a succession of those winds till it attained a much greater height. It sometimes reached a height of from 9 feet to 12 feet, though seldom more than 9 feet. The storm winds which produced this great elevation were rare. When they occurred they stirred up the water for a considerable distance outside, rendering it very

muddy. The mud and sand were of course brought over the low land with the water, and on the retiring of the water, were left behind; the operation to a certain extent working its own cure. It was not like the great waves of the Atlantic, rushing in and breaking down the dykes on the coast of Holland, and carrying destruction with them. It was rather the addition of a large quantity of sand to the general line of the coast,—the breaking down, it might be, of a portion of the coast, and the removal of the sand a little further inland; and therefore it was, that by carrying the dyke a little way within the general coast line, the effects of these great elevations of the sea were really harmless. There was a length of about 16 miles of this dyke and ditch—a ridge on one side and a ditch on the other—running along the sea margin of the lower part of the delta of the Rhone, and this was found sufficient to keep the sea from ravaging the interior of the delta under the most unfavourable circumstances. During the many years that had elapsed since this line of dyke was formed, no breach had been made in it, though there had been numerous instances of high water and extraordinary storms.

The case was not altogether the same with regard to those portions of the district beyond the line of the main delta, and which he had called the pseudo-delta of the Rhone. By this expression he meant the deposit which extended far beyond the range of the ordinary delta, though it was derived from the mud brought down by the stream. Within this range there was a space of 60 miles or 70 miles in length, and of considerable breadth, along the whole of which there was a succession of lagoons, within the outer line of the coast. These lagoons were generally shallow, connected with rivers, and almost without exception unhealthy. The object of works carried on, then, would be partly to diminish the unhealthy condition of the coast, and partly to bring into cultivation a tract of 20,000 acres or 30,000 acres of marsh lands, now of scarcely any value, but which, with a moderate amount of attention and care, might be rendered available for agricultural purposes. It was not to be supposed that this tract could be rendered altogether salubrious, because no marsh lands on the shores of a great inland sea like the Mediterranean could be, under any circumstances, perfectly healthy. Considerable improvement might, however, be effected in the most unhealthy places; and that was an advantage which might be expressed in figures, and would be perfectly recognized in the immediate neighbourhood. The works intended to be carried out were divided into two sections. With regard to both of these, however, he ought to mention that there was already a basis of operations, consisting of an important canal, called the Canal des Etangs, or Canal of the Lagoons, constructed

to convey the produce of the Mediterranean into the interior of France, commencing with the town of Cette, on the lagoon of Thau, and communicating at the extremity of the lagoon with another canal, called the Canal de Beaucaire, which entered the Rhone at Tarascon. Those canals were in the middle ages of great importance. Beaucaire was at that time the seat of a large fair, which was still continued. The canal cut across the whole chain of the lagoons, and was the receptacle for the water drained, and the means of conveying the water lifted to the sea. Dividing the district into sections and basins, it was proposed to treat each separately, conveying the water from the higher level marshes by cuts into transverse drains, and thence into deeper drains alongside the main canal, whence the water would be lifted into the canal and be allowed to run off. It was also proposed to form several direct communications in each section from this canal to the Mediterranean, in order to carry the water off more easily. The water was to be lifted by pumps worked by windmills. It would be seen that the whole method was exceedingly simple, and involved no new processes of engineering. The general result would be, that the lands surrounding the lagoons would be completely drained, and two lagoons left whose waters would be uniformly salt, or nearly so, and whose level would be the same in summer and in winter, and in this way the country around would be rendered healthy.

On Plate 14 he had indicated the works which had been designed by M. Régy, the Engineer-in-Chief of the Department, and which it was proposed should be constructed at the expense of Government. He believed, before long, the result would be, as he had explained, to reduce this system of lagoons into two sheets of salt water, at a permanent level, instead of a number of sheets of water alternately fresh and salt, at levels constantly changing. A large quantity of the drained land would be also available for agricultural purposes.

The works projected with regard to the lagoons of Corsica were of the same general character. They had not yet been sanctioned by the Government, but it had been suggested by him to divide the lagoons into two parts, and to drain the southern portion, leaving the northern part entirely open to the salt water.

The works he had referred to were of the greatest possible importance locally; and no doubt many other extensive districts of the Mediterranean shores, affected by malaria, might be rendered habitable and healthy by the application of similar principles. Everything connected with the subject deserved careful consideration, because such works were not always successful, and any permanent success would doubtless lead to similar works being under-

taken in other districts. Every one who knew the shores of the Mediterranean would be aware that there was an opening for these engineering works, and to what an extent the country was at present suffering from the neglect of general drainage operations.

Mr. R. Mallet had on two occasions examined the districts forming the subject of the Paper, the last time with considerable care, and had made himself acquainted with the professional literature of the subject. He considered that Papers of this class were of extreme value and interest to engineers, whose highest task was undoubtedly the remodelling and fitting for the use and comforts of man, the great features of the world, effecting, upon the vastest scale, that which was man's inheritance and duty—the replenishing the earth and subduing it. But in order to do that, the principles on which Nature acted, in forming those features which had to be modified or changed, must be thoroughly understood. He had expected, therefore, that Professor Ansted would have given some definite and distinct theory as to the mechanism by which lagoons, such as those of the Mediterranean shores, were formed; but he had failed to find any such theory clearly enunciated. Professor Ansted's view appeared to be, according to the Paper, that those elongated though irregular sand-banks, which constituted the barriers between the lagoons and the Mediterranean, were produced by the silt brought down by the waters of the Rhone. That impression was, however, somewhat modified by the remarks Professor Ansted had since made, from which, so far as Mr. Mallet understood, the sources of these deposits were left unaccounted for, and were said to have been thrown up by the sea. In any case, no specific natural mechanism had been assigned as to how this took place, or why the sea produced these lagoons. It was known that on many coasts the sea was muddy and charged with sediment, yet no lagoons were formed; nor could he see that any distinction had been shown between the natural mechanism which produced deltas, and that which produced lagoons. He was not now going to introduce any theory of his own, but this subject had been handled with the utmost ability by French engineers. M. Régy, of the Corps des Ponts et Chaussées, had in fact evolved a most complete and satisfactory theory, accounting for the formation of the lagoons on the shores of the Mediterranean.[1] The word 'lagoon' was used in a most general way by geologists: he had looked into all the standard English authors on Physical Geology and Geography for any precise views as to the nature of the formation of littoral lagoons, but he found they were absolutely barren on the subject, and to the last degree hazy and unsatisfactory.

[1] *Vide* "Annales des Ponts et Chaussées." 4e Série, tome v., p. 220.

Professor Ansted, in his 'Physical Geography,'[1] stated, in a single paragraph, all he had to say on this matter, as follows:—

"Running water, bringing with it large quantities of detritus and mud, deposits a large proportion of this foreign material where it comes in contact with still water, whether fresh or salt, and thus there is a tendency to choke up lakes of moderate size. Near the sea, however, at the mouths of great rivers, or even where the actual streams are inconsiderable, a barrier often grows up beyond the ordinary limits of land. This is especially common in long lines of flat coast. In such cases the barrier becomes in course of time a long strip of low land, open, perhaps, to the sea at one or two points, but enclosing a long tract of shallow water. Such is the long spit of land called the Lido, that protects Venice from the sea and forms the *Lagoon*. Lagoons are lakes often shallow, formed artificially near the sea, where the level of the fresh water within the barrier or reef is the same as that of the sea immediately outside, and where there is little current of the water, either entering or emerging.

"Such are the varieties of lakes. &c."

This confounded the phenomena resulting in deltas with those giving rise to lagoons, and did not throw light on the mechanisms producing each, which were radically different. Now there were many places on the English coasts where the sea was continually throwing up matter, but without forming lagoons. One instance was the Chesil Bank; but there was no large lagoon there, nor could there possibly be any, through the form of Portland Roads. Something more, therefore, was necessary than the sea casting up material upon a coast to produce a great lagoon. The explanation given by Mr. Régy might be briefly hinted at: a shore sloped steeply at first and then more gently further seaward; though sediment was brought up it formed no lagoon, for every particle was kept suspended until it came on shore. But if, on the contrary, the shore had a gentle and gradual slope, such as that of the Mediterranean, where the mean slope was for large areas not greater than about $\frac{3}{16}$ths of an inch to the yard, the sea which rolled in on such a coast formed breakers at different distances from the shore, dependent upon the magnitude of the waves, those which were largest breaking farthest out from the shore, and all of them, of whatever dimensions, where the roller reached water of a depth equal, or nearly so, to its own height. At each such line of breaking waves, there was comparative still water, from the spreading or deploying of the breakers after they lost the wave-form and fell into the water around in foam and spray. Where those lines of still water occurred, there was a deposit from the muddy or sandy water, and thus the sloping bottom got altered into a surface consisting of a succession of more or less parallel, but at first very flat hills and hollows. These increased in magnitude, as well as were driven further in shore,—at length

[1] *Vide* Edition of 1868, pp. 179, 180.

came above low water, were then helped by blown sands driven by prevailing off-shore winds, and at last the innermost bank isolated the shallow in-shore sea within it more or less completely, and so a lagoon was established. This simple but most curious train of causation being once understood, it was quite unnecessary to call in river action, which might, however, if the rivers fell into the lagoon, greatly modify its subsequent history. As regarded the source of the supply of mud and sand, it had been shown satisfactorily by French geologists, that the entire detritus of the Rhone would be insufficient to furnish the material heaped up in the production of the lagoons of the Mediterranean, and it had not been proved that more than a small proportion could at present come from the existing delta of the Rhone. The great plain called the Crau was a mass of extremely ancient detritus, carried down from the Alps of Dauphiné. Its average level was about 40 mètres above the level of the sea: it formed the last remains of the great under-sea deposits that were swept down the valley of the Rhone when the south of France was at a much lower level than now, and when the tidal estuary extended miles up the valley. The Crau was the heavy detritus brought down, probably at a time when the Mediterranean had higher tides than now, and when, by marine sorting action, the finer material was carried far out to sea. The largest portion of the material, out of which the generally elongated dunes that isolated the lagoons from the sea were formed, came from the bottom of the Mediterranean, where it had been laid, and not from the Rhone of the present day. It had been shown by M. Régy, in proof of this, that the material consisted of about two-thirds silicious sand and one-third carbonate of lime, which last consisted almost wholly of comminuted sea-shells of recent marine species, and therefore could not have come from the river. It was but just to remark that M. Duponchel, a previous Author in the Annales des Ponts et Chaussées,[1] was disposed to attribute a good deal more to the deposits of the Rhone in producing these lagoons than M. Régy was prepared to admit; but he thought M. Duponchel's views could be satisfactorily disposed of. In fact, if the delta-forming forces and mechanism of this river were sufficient to make these lagoons, there was an end of any distinction between a delta and a lagoon, or between the wholly different mechanisms by which each was formed. A delta might no doubt at its debouchure lap round more or less its former shore, so as to gradually include certain irregular ponds of water which simulated lagoons; but the lagoons referred to were small inland seas, and were 6 fathoms deep in some places. He would say further

[1] *Vide* 4e Série, tome ii., p. 160.

that many of the largest lagoons in the world were found in situations where no great rivers discharged into them, and where, in fact, no great rivers existed in the neighbourhood. He might mention, as one small instance, the bank called the Murrough of Wicklow, on the shores of the Irish Sea. The little streams which came down along the whole length of this great bank of sand, with a long lagoon behind it, were incapable of supplying the mass of material in that bank; and it was obvious that the source of the material which had formed the bank was from the sea. Again, in France, on the shores of the Gulf of Gascony, at the well-known 'Landes' of Bordeaux, there were many lagoons equal in size to the largest lagoon described in the Paper; but along the entire length of the 'Landes,' between the river Garonne on the north and the Adour on the south, there was not to be found a single large river. Even in the case of Corsica, there was not one large stream delivering into the lagoon of Biguglia. There was the Golo, a large torrential stream, but that fell into the sea outside the lagoon. Still it might supply some material: and it was equally true of the shore of the south of France, that whatever the Rhone brought down would, by the prevailing marine currents, be carried past the shore, and thus add *pro tanto* to that great supply which was carried up and brought in by the sea. To judge what the deposit and what the disturbance of the Mediterranean bottom of the Gulf of Lyons were capable of doing, he might state that when he was in this district about five years ago, it being then winter time, there had been a gale of wind from the south and south-east blowing for several days. At Cette he learned that the sea was then $2\frac{1}{2}$ mètres above its average level, and breakers 8 feet or 9 feet high were coming in, and as far as the eye could reach for miles out to sea the water was of a deep red-brown colour from suspended matter. With regard to the works proposed to be carried out, it was obvious that the attempt to deal with lagoons like these was among the most complicated problems which an engineer could have to grapple with. It was not the fact that the waters of the lagoons were either all salt or all fresh: their surfaces were at various and perpetually changing levels, and there were all degrees of saltness—from that of brine which yielded 1 kilogramme of salt to 9 kilogrammes of water, down to comparative brackishness. Some of these lagoons were real inland seas, of considerable depth over large areas, with valuable fish in them, and navigated by vessels with large latteen sails. These could not be judiciously destroyed, and in fact there was no means of laying them dry. Their levels might perhaps be lowered to a certain extent, but he apprehended that would only aggravate their malarious tendency, without being of any service, and destroy their present utility. Many were

formed from fresh water, and many had fresh-water springs in the bottom. Some were masses of green vegetable slime, and nearly dry for five months or six months of the year: others had as pure water as the Mediterranean at all times. The first question, therefore, was to decide, upon economical and social considerations, which lagoons ought to be meddled with and which let alone, and these were questions of extreme intricacy. These considerations M. Duponchel had, in the broadest way, entered upon and discussed. Much in the way of improvement had been done and many works executed, extending over long periods of time. In 1863 the French Government voted 8,000,000 francs for the improvement of this region, by further works generally based on the recommendation of M. Duponchel and others. But all that had been decided upon might be roughly described as the execution of canals, intended to cut off the upland waters and deliver them out at sea; to cut up the shallow lagoons into small regions by 'polders,' and to lay them dry by steam power; to fix the migratory banks and surfaces by judicious but not very costly works; and to call Nature to the aid of the engineer, by the plantation of the surfaces with well chosen shrubs, such as *Tamarix Gallica*, and trees.

Mr. J. T. Harrison observed that the Rhone drained a region of about 37,000 square miles, very nearly six times as extensive as the Thames basin, and two-thirds the area of England. He wished specially to direct attention to one point, the quantity of material forming part of the ancient delta of the Rhone which had been removed during the formation of the modern delta. As far as he could judge, the existence of the modern delta resulted from a comparatively recent elevation of the old delta many feet above the sea, in consequence of which the Rhone had to make its passage through the old delta. It appeared that, besides the existing channel, there were three distinct but abandoned main channels of the Rhone: 'the Dead Rhone,' 'the Little Rhone,' and 'the Old Rhone;' and in the Paper it was stated that the Rhone "had been steadily advancing eastward for a very long time." He thought it probable that, soon after the elevation of the ancient delta, the Rhone discharged by the old channel of the Vidourle, along with that river, into the Gulf of Lyons; and this accorded with the description of the limits of the true or modern delta. He looked upon the cultivated portion of the delta of the Rhone as the site of part of the ancient delta denuded to its present level; and he believed the modern delta was formed of materials supplied by the ordinary detritus of the Rhone, but principally by the gravel removed from the ancient delta. When the Rhone discharged by the old channel of the Vidourle, the ancient delta, elevated considerably above

the sea, would cover the space between the line eastward from the mouth of the Vidourle and the gravel-hills, and it would be encroached upon by the sea on the one side and by the Rhone on the other. From the direction of the coast line, the waves raised by the south-east winds would drift shingle to that part which lay between Cette and the mouth of the Lez, both from the eastern and the western shores of the Gulf of Lyons; this the peculiar convex form of the shingle beach seemed to prove. With the Rhone carrying coarse gravel to its mouth, in addition to the ordinary detritus, and the sea encroaching upon the gravel cliffs of the ancient delta, and driving the shingle towards the mouth of the Rhone, the result would be the formation of a spit similar to those formed in numerous instances across the estuaries on the coasts of England, some of which, as that at the mouth of the Exe, enclosed lagoons. Such a spit separated the lagoon of Mauguio from the sea; and he thought it probable that the mouth of the Rhone was, by the formation of this spit, driven westward to near the mouth of the River Lez. The extensive marshes on the land side were confirmatory of this view, as the Rhone would maintain a clear channel near the sea, whilst the mud was deposited towards the land in the still shallow water. As the river encroached on the old raised gravel delta on the one side and the sea on the other, these would eventually meet, and the Rhone would be discharged by a new channel, possibly that marked 'the Dead Rhone,' leaving the spit an island at first, but eventually enclosing the lagoon of Mauguio, where the sand-hills were thrown up. With this much shorter course the Rhone would deepen its channel, encroach more easily upon the ancient delta, and thus increase the quantity of material discharged by it; and it would rapidly extend its delta on the shallow bed of the sea—shallow because recently encroached upon by the sea. Thus would be formed that "first step" mentioned by Professor Ansted. As the delta was projected considerably beyond the coast line of gravel, and as it extended and spread out, the velocity of the Rhone would be so diminished that a bar would form, as in every river carrying large quantities of matter into a shallow sea; and the Rhone would break across the delta at the point of least resistance, as ere long it would probably do from its existing channel into the bay to the eastward of the delta it was now forming. Thus it would appear a mouth was formed considerably to the eastward of 'the Dead Rhone,' from which position the shingle moving along the beach drove it westward to the mouth called 'the Little Rhone.' Again, an entirely new and shorter channel seemed to have been formed more in the line of that now existing, with great facilities for the river to encroach on the gravel of the old delta, followed by a rapid extension of the modern delta; thus he accounted for the "second

step" mentioned in the Paper, and 'the Old Rhone' remained to show the spot at which the river was then discharged. From similar causes to those already described, the formation of a bar and the obstruction thus created, the river was eventually diverted into its present channel, which in turn would be abandoned for one into the bay to the eastward of it. The formation of these spits and of the delta in the manner described was a distinct operation of Nature from the throwing up of the sand-hills; the delta proper and the spits were the necessary precursors of the sand-hills, and they determined their position. The manner in which the sand-hills or dunes were thrown up by the sea and blown together by the wind had already been explained, but their position, and the enclosure by them of the lagoon both on the delta itself and along the coast, were dependent upon the previous foundation laid by the drifted shingle and by the bar formed at the mouth of the river.

Mr. Hawkshaw, Past President, remarked that, unless the discussion based upon the Paper was made more applicable to subjects which engineers usually considered—viz., the means to be adopted for the abatement of the inconveniences complained of—but little practical advantage would be gained. He thought the present line of discussion was more suitable for the Geological or the Geographical Societies.

Mr. Pole exhibited and explained a map of the largest and best known of the Mediterranean lagoons, one renowned in history, poetry, and art, as well as celebrated for its engineering works,—the lagoon of Venice. This city, as was well known, stood on a cluster of islands, in the middle of a large salt-water lagoon, about 25 miles long by 6 miles or 7 miles broad, and separated from the main Adriatic by a narrow strip or bank of land. The bank was protected by artificial works, where necessary, against the action of the sea, and it had several openings, or 'Porti,' to give access to the lagoon. One of these, the 'Porto del Lido,' nearly opposite the city, was most used by small vessels, but ships of large draft were obliged to go to the 'Porto di Malamocco,' a few miles to the southward, where deeper water existed. This port had some years ago been much improved by the erection of two breakwaters projecting out to seaward, one of which was upwards of a mile long, and which were intended to deepen and straighten the entrance channel. By this port ships of large tonnage could get into the lagoon, and so up to Venice. The lagoon consisted of two parts, one entirely of water, called the 'Laguna Viva;' the other, nearer the land side, consisting of land broken up by numerous channels, called the 'Laguna Morta.' The former was used principally for navigation, and had, in the fair-way channels, a depth of upwards of 20 feet, and many important towns and villages were situated

in it or upon its banks. The 'Laguna Morta' formed a great fishing-ground, supplying nearly the whole of north-western Italy. The communication by railway from Venice to the mainland was carried across a part of the lagoon on a fine bridge of masonry, 2 miles in length, which would be well known to those who had visited the city.

The particulars most interesting to the Institution would, however, be those connected with the hydraulic engineering of the lagoon. It had been obviously formed by the agency of several large rivers, draining north-western Italy, and which debouched into the sea at this place. The more important of these were (beginning from the northward) the Piave, the Sile, the Brenta, the Bacchiglione, and the Adige, which latter came in at the southern extremity. Many of these originally debouched into the lagoons; but the Venetians saw, at an early period of their history, that it was exceedingly desirable to exclude them, for two reasons. In the first place, the fine detritus which was brought down in large quantities silted up the channel, and threatened in course of time to turn the whole lagoon into dry land; and secondly, the introduction of the fresh water, and the formation of marshes, endangered the healthiness of the locality, and possibly would sooner or later render the city uninhabitable.

At first attention was directed to the Brenta, which, coming from Padua, entered the lagoon directly opposite Venice, and therefore was the most mischievous. The interests of the Venetians were, in this respect, opposed to those of the inhabitants of *terra firma*, who naturally wished to have the mouth of their great arterial drain unimpaired; and from the 12th century onwards this question formed a standing source of dispute between Venice and Padua, which was not unfrequently enlivened by passages of arms. As, however, the Venetians gradually gained power on the mainland, they put their privileges in force by attacking the mouths of the rivers. About the middle of the 14th century, they diverted the mouth of the Brenta from opposite the city to a point a few miles lower down; but a century later, doubts were raised as to the policy of this measure, on an argument often considered of great weight in reasonings about rivers and estuaries in the present day, namely, that the fresh-water current, so far from being prejudicial, was really beneficial and necessary as a means of scouring out the channels. This reasoning was allowed to prevail, and the Brenta was restored to its original course; but the rapid silting up which at once set in soon proved the correctness of the earlier opinion, and after a few years the diversion was again resorted to. But it was now seen, that the position of the mouth formerly adopted, though clear of the city, would throw the waters upon the Port of Malamacco, which then began to assume more importance as a

deep-water channel; and to prevent the silting up of this, it was resolved to carry the embouchure of the river still further away. The Venetians subsequently desired to protect the lagoon still more perfectly, and, after many intermediate stages of alteration, they at last succeeded in entirely excluding from the lagoon not only the Brenta, but all the other rivers. These operations extended over several hundred years, and involved engineering operations of enormous magnitude, the whole lagoon being surrounded with great engineering works for its protection, both towards the land and the sea.

In these measures the Venetians had thought only of themselves, caring little as to what effect their meddling with the rivers would have upon the interests of *terra firma;* and this neglect was apparently not accidental, but wilful, as it was on record that they carefully excluded from their earlier deliberations those who were connected with property on the mainland. But the matter was so serious that it soon forced itself upon their attention. In the diversion of the Brenta, they had lengthened its course 15 or 16 miles, thereby much diminishing its angle of inclination and power of discharge; and in that flat country, where already the rivers were scarcely capable of effecting the drainage, the consequences of this alteration became manifest in great inundations and extensive damage, whenever the seasons came that put most work on the drainage system. Other causes were said to have increased the evil, particularly the gradual cutting down of the forests in the mountainous districts, which prevented much absorption of rainfall. By the middle of the 18th century the evils had become public calamities, and it was impossible they could be any longer ignored.

From this period the subject underwent a course of discussion and controversy which had become memorable in the history of European engineering; a great number of opposing opinions being held, as to the best mode of meeting the acknowledged difficulties of the case. About 1785, the Government, to gain time and satisfy the urgent calls for action, issued a general invitation to all Europe for plans to be sent in; and the invitation was so largely responded to, that the magistracy were in more perplexity than ever. They adopted the extraordinary course of referring the plans to a lawyer, a certain Signor Artico, the fiscal advocate of the magistracy, giving him instructions to examine and report on all the designs submitted. This personage, though he did not appear to have known anything of the subject originally, took the wise precaution of studying it well before giving any decision; and being naturally clever, he succeeded in so far mastering its technicalities, as to understand the merits of the various schemes. But more than this; he did not recommend any scheme entirely, but adopted a plan not unknown in other

engineering cases; he took the salient points of the best schemes, and combined them into a new plan of his own, which, under the name of the 'Sistema Artico,' received subsequently much attention, and was considered deserving of great credit.

The European disturbances that followed a few years later prevented anything being done; but the subject was taken up again by the Austrian Government in 1804, and by the Italian Government a little later. In 1807 Napoleon visited Venice, and wishing to connect his name with an act of imperial munificence to the city, he issued a summary approval of Artico's plan, ordering it to be at once carried into execution. This approval was given on the recommendation of the two celebrated hydraulic Engineers, Prony and Sganzin, who happened to be in Venice at the time; but it was shown soon afterwards that there were defects in the plan, and though something was done towards it, its general execution was delayed, and the convulsions of Europe a few years afterwards brought the matter again to a stand.

The land provinces then demanded the re-introduction of the rivers into the lagoon; the Venetians resisted this strongly, imploring the Government to complete Artico's plan; but the authorities were so much divided in opinion that nothing could be agreed on. In the meantime came the great flood of 1816, which did damage to the amount of above 12 millions of francs, and the result of which was to bring up more new plans and more discussions, that involved the matter in a greater chaos than ever. More devastation followed in 1823, 1825, and 1827; and in 1829 the Government resolved to submit the whole question to the judgment of a certain Count Vittorio Fossombroni, a man of eminence, who had particularly distinguished himself in knowledge of the science of hydraulics, and in practical good sense in its application. He took some years to examine into the matter, and called in the aid of Signor Pietro Paleocapa, an engineer of great eminence in Northern Italy; and in 1835 he presented to the Government a memoir,[1] entitled 'Considerazioni sopra il Sistema Idraulico dei Paesi Veneti.' The principal feature of this plan was the re-introduction of the Brenta into the southern part of the lagoon, far away from either Venice or Malamocco, where its deposits could do little harm, but which would materially shorten its length of course. But Fossombroni had also found that the levels had been badly laid out, and that by correcting these, and by making certain rectifications and cuts, he could materially increase the discharging power. In fact his plan, with the exception of the main change in the mouth of the Brenta, consisted rather in improvements in detail, than in any great alterations of system.

[1] Afterwards published by his widow, with an introduction by Signor Paleocapa. Florence, 1847.

This plan was submitted to the authorities and was much discussed; but as the years from 1827 to 1839 were remarkably free from inundations, this immunity gave excuse for further delay. In the latter year, however, another frightful flood occurred, followed by repairs that cost more than a third of the money that would have been necessary to carry out the remedial measures. The Viceroy, now out of patience, visited the works in person, and ordered the main feature of Fossombroni's plan—the change in the mouth of the Brenta—to be at once carried out; and in April, 1840, the river again entered the lagoon, after centuries of exclusion. This gave immediate relief; for though in succeeding years heavy floods occurred, no great damage was done. The other details of Fossombroni's plan were then discussed and approved, and some years ago they were in course of execution.

Mr. Pole confessed that, on visiting Venice during the latter part of the Austrian rule, he had been much pleased to see the attention that Government was giving in the way of preservation and restoration, and he sincerely hoped that, under the national Italian Government, equal care would be bestowed on this grand old city.

Mr. Redman contended that whether or not the Paper was likely to produce a discussion more congenial to the Geological Society or to the Geographical Society than to The Institution of Civil Engineers, it was hardly fair to the Author, either that the discussion should be shortened, or that the Paper itself should receive anything like *sub silentio* treatment. Besides the Mediterranean lagoons, those of the western coast below Bordeaux, which were of considerable extent, had likewise been referred to. Many of these were not connected with rivers, and certainly were not estuaries of tidal rivers; at the same time they possessed all the deleterious qualities ascribed to lagoons generally, as producing malaria and its concomitant evils. There was an opening for engineering practice in these districts, where there was a range of tide of 12 feet or 14 feet, which did not exist in the Mediterranean. This would be a great assistance in carrying out works on the borders of these lagoons. With reference to the age of these formations, no doubt, as the Author stated, geologically they were modern, but as regarded the ordinary affairs of life, the antiquity of the lagoons appeared to leave no room for question. There had been learned disquisitions as to whether the seaboard of the lagoons south of Nismes and west of the little Rhone, coincided during the Crusades with that now existing. Some writers had detected ancient works, in the shape of a silted-up canal, and a wharf bearing a local name, which favoured the supposition, that the sea-board of the present day, and that of the time of St. Louis, were nearly identical. Then these lagoons were situated upon a tideless sea.

The lagoons on the eastern coast of Corsica existed under similar conditions, as also the lagoons on the opposite ancient Etruscan coast. At the head of the Adriatic there was an oscillation of tide of 5 feet, which, to a certain extent, altered the conditions attendant upon the Venetian lagoons. On the coasts of Great Britain there were formations identical in origin with the lagoons of the Mediterranean, and of great antiquity, as evidenced by the Danish works within the sand dunes at Holkham, in Norfolk, and elsewhere. There were large tracts of land on the northern and eastern coasts of Norfolk and Suffolk demanding the attention of the engineer, which possessed many of the bad qualities of the Fens, but they offered facilities for engineering operations, as they were close to the sea, where there was a rise of tide of 15 feet to 20 feet, which rendered the reclamation of land easy.

Mr. A. Giles thought the discussion was tending to no practical conclusion, and this emboldened him to ask the Author a question. No doubt many ingenious theories might be adduced for the formation of these deltas; but he was content to take the delta as a fact, and to consider the works suggested for the contemplated improvements. Unquestionably, the atmospheric condition of these coasts could be improved, but he wished to know what these improvements, and the bringing of this land into an agricultural condition, would cost. In England it was very poor land indeed that was not worth £10 per acre, and with the exception of mountain land, there was scarcely any below that value. If the reclamation of the 20,000 acres or 30,000 acres, which the Author spoke of, would require an expenditure not exceeding £200,000 or £300,000, the carrying out such a work would confer a commercial benefit upon that country, as well as a sanitary improvement. He therefore begged to ask the Author whether he could state the probable cost of the works in the drainage and reclamation of the 20,000 acres or 30,000 acres of land.

Professor Ansted replied, that the estimated cost of the works, proposed to be carried out with regard to the lagoons on that part of the coast beyond the delta of the Rhone, did not exceed £53,400. After draining, the land would require a certain amount of washing, to remove the accumulated salt, and he could not positively say what the cost of that might be. No doubt the main object of the operations he had described was to render some large and a number of smaller towns, among them Montpellier, more healthy than they were at present. He did not say that sanitary considerations were more regarded in France than in this country; he believed it was the reverse, but they were not neglected. It was a matter of importance to many large and populous districts, that they should be rendered less unhealthy; and if by the expenditure of even a considerable number of thousands of

pounds more than the value of the agricultural lands reclaimed, these places could be rendered healthy, it was an operation worthy of being carried out. It was not necessary, therefore, to discuss the question, as to whether these particular works would be commercially productive, although he believed they might be, nor did he bring forward the subject with reference to that question. Works were proposed in an important district, which represented lands in many countries, the interest of which must depend on the importance and extent of such cases.

With regard to the origin of these lagoons, he had endeavoured to point out in the Paper, that they were due to the meeting of fresh water, derived from a certain area of land drainage, with the sand conveyed by marine drifts and currents towards the land. In the case of the Gulf of Lyons, the drifts were very remarkable, and during storms an enormous quantity of matter was removed from the bottom of the sea and carried towards the land. It was where this was the case, and the supply of material was incessant, that lagoons would be found. The discussion of such matters had certainly appeared to him to be a subject belonging to the engineering profession. It could not be regarded as a question of geology, with which it could hardly be said to have anything to do, or even of physical geography. At any rate it was not one which could properly be discussed either by the Geological or the Geographical Societies, so far as the drainage of the lands and lagoons and improvement of the sanitary condition of the country were concerned. Would it be said that it was a subject that ought not to be considered at all? He ventured to repeat that an account of operations rendered necessary by certain natural conditions, and only to be carried on effectually by a knowledge of physical geography and geology, but requiring to be executed by engineers, could only be fitly considered by practical men, and could hardly be offered as a communication to any other body than The Institution of Civil Engineers.

Mr. Gregory, President, said he thought the members generally would feel much indebted to Professor Ansted for contributing a Paper to which they would recur with great interest. He was persuaded that the engineer might, with advantage, study the physical geography of a district, with the view of ascertaining the processes by which natural formations arose, or underwent changes, as by such a study the processes of nature might best be utilized or combated; for it frequently became an engineering fact, that "Art is but Nature better understood."

February 23, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

The discussion upon the Paper, No. 1,214, "On the Lagoons and Marshes of the Shores of the Mediterranean," by Professor Ansted, occupied the whole evening, to the exclusion of any other subject.

March 2, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—WILLIAM JOHN FORREST, JOHN JOHNSON, HENRY NATHAN MAYNARD, and EDWARD BALIOL SCOTT, as Members; CLEMENT BARNARD, JOHN HOPWOOD BLAKE, HARRY CHUBB, ARTHUR DOUGLAS FOX, ROBERT ANDREW ROBERTSON, Major JOHN HERON MAXWELL SHAW STEWART, R.E., Captain EDWARD TALBOT THACKERAY, *V.C.*, R.E., and FRANK TURNER, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV., of the Bye-Laws, as Students of the Institution:—JOHN GEORGE BARTON, HERBERT MAUDE BELL, HUGH WHINNEY DALLAS, THOMAS INMAN, SAMUEL MOYLE, and HENRY OLIVER SMITH.

No. 1,220.—"On Sinking Wells for the Foundations of the Piers of the Bridge over the river Jumna, Delhi Railway." By IMRIE BELL, M. Inst. C.E.

THE subject of brick-cylinder foundations has already been brought before the Institution by Colonel Goodwyn, Mr. Bruce, and others;[1] but the apparatus has since been greatly altered, and it will in all probability be superseded, by the use of sand pumps, or, perhaps, by some more modern invention.

The plan of sinking wells, built of masonry or brickwork, for the foundations of walls on the banks of rivers, where the soil is sandy, has been in use by the East Indians for many centuries. The original mode was first to excavate to water level, then to lay a wooden curb, rather larger in diameter than the well, and upon this curb the brickwork of the cylinder or well was built to a height of 8 feet or 10 feet. The sand was excavated from the interior with a spade, shaped like a large adze, and called a phoura, to the depth of 5 feet, when building and sinking were alternately proceeded with, till the required depth of foundation was obtained.

The first length of 5 feet is accomplished in a couple of days; but after this the rate of sinking decreases according as the depth increases. The jham is used after the first 5 feet. This is an im-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 63, xvi., p. 455, and xvi., p. 449.

plement similar in shape to the phoura, only much larger, being about 2 feet 6 inches long, and 2 feet broad (Plate 16, Fig. 1). The rope B is lowered down inside the well, and the man puts his feet at A, on the top edge of the blade of the jham, and, grasping the wooden handle at C, dives down, and buries it as deeply in the sand as he can, returning at once to the surface of the water, where he rests on a board slung inside the well. The rope B is then hauled up, and the sand removed, when the jham is again lowered, and the operation repeated. The removal of material from the inside causes the well or cylinder to sink by its own weight. Where this is not sufficient, an ingenious and cheap method is adopted, as follows:— The top of the well is covered with planking, projecting about a foot or so beyond the outside of the well; upon this two cylinders, one the size of the inside of the well, and the other, or outer one, 2 feet greater in diameter than the outside of the well, are built; these are composed of large ropes, made of long grass twisted, pinned with wooden pegs, and strengthened with ties and struts of timber; the space between these cylinders or walls is then filled with the material excavated from the well. This is in some cases carried as high as from 15 feet to 20 feet, which gives a weight of about 5 tons for each foot in height. This operation is, of course, tedious, and, in fact, quite unsuitable for large bridges where the foundations have to be carried to a greater depth than 25 feet, as the expense and loss of time are very great.

On the railway bridge over the Jumna at Allahabad, in the construction of which the Author was engaged, in executive charge of the southern half, from 1860 till its completion in 1865, the jham was used in sinking the wells for the foundations of the piers and abutments, with a pole, instead of by sending down a diver, after the first 10 feet. The manner in which this was done was as follows:—Plate 16, Fig. 2. The jham was lowered by a couple of ropes A to the bottom of the well, and when the cutting edge of the spade or jham B touched the sand, the chain E was hauled nearly tight, and left with a single turn round a bamboo, so that it could easily be payed out as the jham was driven into the ground. The vertical pole C was then drawn up about a foot by a double rope G fixed at the bottom of it, and being let go with a jerk, struck the butt of the jham with considerable force, and drove the jham into the sand. This operation was repeated till the jham was down to its full depth. The pole C was then pulled up a sufficient length to release the pin F, which worked loosely in the eye through the butt of the bar D, and let drop clear of the jham; the chain E was then wound up by a windlass at the top of the well, bringing up the jham filled with stuff to the top, where it was emptied. The chain was then unwound, and the jham lowered again, and the same process repeated till the well

was sunk to the required depth. In some cases the jham and pole were lifted together a foot high, and let drop again, which was a similar operation to the navvy with his spade. It depends very much upon the nature of the material which method should be adopted, and also upon the way which the men have been accustomed to, as the natives of India are thorough conservatives, and dislike changing the customs of their fathers in the slightest manner.

This plan is a decided improvement upon the old native way of sending down a diver, but still it is tedious and slow, especially where strata of clay or till are met with. This was the case at one of the piers of the Jumna bridge, where a bed of dark, hard till and stones was come upon, at a depth of 38 feet below low water, and the wells could only be sunk about 1 inch a week, although weighted with nearly 100 tons of rails on each well. These wells were ultimately left at this depth, as it was presumed the hard till would resist the scour of the river, if it ever did scour so deep.

In each pier of this bridge there was a group of ten wells, two rows of four in each row, with one on the up and another on the down stream side for cutwaters. From the Author's experience in well sinking, he is of opinion that it would be preferable to have only one row, as there is continual trouble in some of the wells in either line getting off the plumb, and becoming jammed either against the top or the bottom of the ones opposite. Very often in removing the stuff from under one side of the curb, to bring it back to the perpendicular, the opposite well would lean over, from the stuff running from under its curb at the same part. In order to avoid this, and to insure speedier sinking, a plan might be adopted of having only one row of wells in the breadth of the pier, which would generally not necessitate a larger well than 18 feet in diameter, the sinking of which could be easily managed.

The well-sinking was proceeded with continuously, there being day and night shifts of labourers, ten men and a mate, or overseer, for each well, and the average rate of sinking was—

For the first ten feet	= five feet per week.
From ten to twenty feet	= three feet per week.
From twenty to thirty feet	= two feet per week.
From thirty to forty feet	= one foot two inches per week.
From forty feet	= six to four inches per week.

The labour was paid by a system of task-work at the following rates:—For the first five feet ten shillings, and for every additional foot up to ten feet ten shillings more, and so on, fifty shillings for every additional five feet. As a rule this satisfied the men and paid them very fairly; but occasionally where hard strata were met with an addition to the rate had to be made, or the divers with Siebe's diving dresses had to go down and excavate the stuff, and let the

well sink through the bed of kunkur, or other hard material, and then the task-work was recommenced.

The bridge, the foundations of which form the more immediate subject of this Paper, is on the Delhi railway, and crosses the river Jumna about 37 miles south-east from Umballa, near a village called Sirsawa, which is situated about lat. 30° 1′ north, and long. 77° 28′ east. The banks at the crossing are well defined, but will require protecting groynes, so as to keep the water in its proper channel, as, like other Indian rivers with banks composed of a sandy soil, it is constantly changing its course. The Jumna takes its rise in the Himalayas, and debouches into the plains at a place called Hatni Koond, where the canal heads are formed for diverting the water into the Eastern and Western Jumna canals. The bed of the river at this place consists of large boulders, from 14 lbs. weight and upwards; this continues to within about 6 miles above the bridge, when it gradually changes to gravel and coarse sharp sand. From borings, and also from the stuff excavated from the wells, it was found that during floods, when the velocity of the river reaches 8 miles an hour, as it did in the rainy season of 1867, the large boulders are brought down as far as the site of the bridge, and are deposited by the scour of the current as deep as 30 feet below the level of the bed of the river in the dry season. As the level of the water falls at the end of the rainy season, the stones decrease in size, till the bed changes to coarse and fine gravel and coarse and fine sand, and over this a deposit of very fine sand and silt. The section is as follows:—

2 feet alluvial soil.
18 feet fine sand, in some places mixed with earth, clay, and kunkur.
5 feet coarse sharp sand, fit for building purposes.
5 feet coarse sharp sand, with gravel.
12 feet coarse sand and gravel, interspersed with layers of blue clay, from 6 inches to 2 feet thick.
5 feet coarse gravel, and boulders of limestone and quartz.
2 feet large boulders up to 15 lbs. weight.
4 feet coarse gravel, sand, boulders, with layers of stiff blue and yellow clay.

53 feet.

There are twenty four openings, each having a waterway of 99 feet in the clear. The total length between the abutments is 2,663 feet 6 inches, thus leaving a waterway of 2,376 feet. The superstructure consists of two lines of lattice girders, resting on single brick columns, each 12 feet 6 inches external diameter. The rails are 29 feet 6 inches above low-water level, and are fixed to longitudinal timbers, which are bolted down upon the girders. There is a footpath on each side supported upon cantilevers projecting from and riveted to the girders, and protected by a light wrought-iron railing.

The working season at this bridge was during the months between October and June, for operations in the bed of the river, brick-

making, and lime-burning; but the work in the shops could be carried on during the whole year, except when there were extraordinary floods, as in 1867, when the river rose 2 feet higher than the banks, and inundated the country for nearly 2 miles on either side. The river showed a strong tendency to scour away the east bank; and the plan first adopted for its protection, was to throw out a series of spurs at the places where the river seemed inclined to flow towards the centre of the channel. This was done by driving two lines of piles, and filling the space between with bags of the firmest material that could be procured near the sites of the spurs; and the down-stream side was filled up to the level of the bank with earth and sand. But during the following rainy season, the river rose 14 inches higher than the highest floods recorded by the engineers in their preliminary surveys and sections, scoured away the spurs, and cut into the bank about 150 feet. The Author subsequently received instructions to adopt measures for the permanent conservation of the bank, as it was thought the river might burst through the embankment at the back of the abutment of the bridge. On consideration, it was decided to erect a spur or groyne that would tend to divert the scouring force of the river, without seriously impeding the flow of the water. This consisted of three rows of piles of sāl timber, placed at about an angle of 45° to the line of the stream. The first row was driven to a depth of 20 feet below the bed of the river, and the top of piles was cut off at the level of the bed. The second row, about 3 feet behind, was driven about 15 feet below the bed, and the tops of piles were left about 2 feet above the highest recorded flood; the third or back row, about 5 feet behind, was driven in a similar manner to the second row, and left at the same level, the whole being well tied and braced with walings and diagonals, firmly secured with bolts and nuts. The front face on the up-stream side was sloped from the level of the ordinary bed of the river up to the head of the second row of piles, and the surface was planked over with 2-inch boards, spiked to the diagonals at intervals of 2 inches. The entire space between the front and the back rows of piles was filled in with fascines, (made of coarse wicker work,) and stones, sand-bags, and branch wood, so that the water flowed freely through the spur without any violent rush to hurt the bank. This description of spur acted successfully, and although tried severely in 1867 by the strong flood, only one of the three spurs was seriously damaged. These spurs not only protected the bank, but induced sand and silt to deposit at the back, and the bank of the river was brought out about 60 feet beyond the line it occupied before the spurs were erected.

In diverting the river at different points during the dry season, in order to get the sites of the piers clear of water, it was found to be more quickly and economically accomplished by gentle means,

tending to catch the particles of sand held in suspension by the water, than by the rougher mode of forming earthen bunds or dams. The plan generally adopted was to drive a line of piles, or bullees, of saplings, 15 feet to 18 feet long and 6 inches in diameter at the butt, and to bind them firmly with moonj ropes (a species of hemp); then a large bolster, made of long grass, twisted together and bound, was let down in front of the piles, and held in position by sand-bags. It was curious to notice the effect of this day by day. The depth of the water decreased on the down-stream side of the piles; and at the end of two or three weeks, the river was entirely diverted into the other channel, which had been deepened, and slightly widened, in order to assist the operation. Where this plan could not be carried out, owing to too great depth of water, islands were formed for each pier, by driving piles on the up stream side, and binding them together at the water level with moonj rope. These piles were driven in the form of half a circle, and sand-bags were lowered on the down-stream side to the height of 4 feet or 5 feet; and then sand was filled in by coolies with baskets to the height of 5 feet above low water. This height had to be maintained, in case of a sudden rise in the river, by one or both of the canals being shut off for repairs, when the water would rise 4 feet. This happened several times, and was most annoying. The engineers in charge of the canal works could not, in many instances, give the Author notice before closing the sluices, as it was generally on account of some accident to the foundations of bridges, or canal banks, and had to be attended to without delay. The melting of the snows on the Himalayas in the month of April, sometimes sooner, and at others later, according to the season, had likewise to be guarded against, as at that time the river would rise 3 feet to 4 feet in as many hours. This only lasted three or four weeks, but it had to be watched, as it could not be foreseen where the scour might occur.

On the completion of the islands sleepers were laid down, and the segments of the wrought-iron curb, on which rests the brick-work forming the steining of the well, were placed in position and riveted together. Plate 16, Fig. 3, represents one of the curbs, showing that in cross section it is like an inverted right-angle triangle, the height of which is 4 feet and the base 3 feet 7 inches. The outer edge of this curb is 12 feet 6 inches, and the inner edge 5 feet 4 inches, in diameter. These curbs were made in England, were sent out in segments, and were put together in the following manner:—

The gusset plates A, twelve in number, framed with angle irons E, were fixed in position, and temporarily bolted to the outside circular plates, from which they radiated inwards, forming in cross section a V shape; the top of the V being the top segmental plates C, which were placed upon the gusset frames, and fixed with bolts

and drifts to the angle iron ring H, the whole being riveted together. Finally the inside sloping plates D were fixed and riveted to the angle irons E, which finished the operation. The sleepers were then taken away, and the entire curb moved into position in the centre of the pier, when the compartments between the gusset plates A were filled with concrete, composed as follows :—

1 part clean sharp sand.
3 parts broken brick or stone.
1 part fresh burnt lime.

The curb was sunk by men with the phoura and basket, till the upper plate was within 3 inches or 4 inches of the level of the water, when six upright bolts K (two of which are shown in section,) were fixed, and the brickwork of the cylinder or well was commenced. The steining or wall of the well was 3 feet 4 inches thick, and the inside diameter was 5 feet 10 inches. When the building had been carried up 6 feet, the well was sunk by means of the jham and divers in the old native style, then 10 feet additional were built, and sunk by the sand-pump (to be hereafter described) worked by a steam hoist of 4 H.P.; then another length of 15 feet was built, and sunk in the same manner, after which the final 15 feet were built, and sunk, which carried the well down to its full depth.

Well sinking, or cylinder sinking, is an extremely simple and easy operation, if care and attention are given to it. The Author has found, from an experience extending over nearly nine years in India upon bridge works, that the main point to be attended to is to get the well fair and straight for the first 10 feet, and there is not much to fear after that. To insure this the curb should invariably be sunk alone, without any building, and after this, care should be taken not to build to a greater height than 5 feet or 6 feet in the first instance; and the stuff must be regularly taken out, either from the centre of the well, or equally all round. If, notwithstanding these precautions, the well does get out of the perpendicular, immediate measures must be adopted to bring it back to the perpendicular, before the sinking is proceeded with. Previous to building again, upon the 5 feet already built, the top course of the brickwork ought to be removed, so as to insure a thoroughly clean surface for the mortar to adhere to, as the top of the length first built is almost certain to have clay and sand in the joints, which would be prejudicial to the bond and strength of the work, as the workmen, especially in India, could not be depended upon to clean out the joints carefully where required. The second height of brickwork should not exceed 10 feet, and if the strata through which the well has to be sunk is stiff, then the well must be weighted, in order to carry it down. Rails or iron weights are about the easiest handled for weighting, and are much to be preferred to additional height of building, as they occupy less height. It is never advisable to build

more than 15 feet at a time, whatever depth the wells may have to be carried, as there are two great disadvantages, namely, the additional labour in lifting and excavating the material from the inside of the well, due to the greater height, and also, if the well does happen to get out of the plumb, the great height above the ground will act disadvantageously in getting it back again.

The lime used at the works was made from marl, or, more properly, calcareous clay, which was found about 2 feet below the surface, in the bottom of a large jheel, or lake. This could only be excavated in the dry season, as the surface of the ground was under water during six months in the year from the rains. When the clay is first dug it is about the consistency of glaziers' putty, and of much the same colour; but it rapidly hardens on exposure to the atmosphere. The native style of manipulating and burning it is most objectionable. After being excavated, it is mixed with a large proportion of cow-dung, or ooplah, and kneaded into small lumps, which, when quite dry, are packed in a circular form of clamp, with additional ooplah, straw, and rubbish. The whole is then covered with a layer of clay, the fire is lighted, and allowed to burn for some days. It is left to cool for a couple of days, and then opened up and the lime taken out, but in a very impure state, as there is a large per-centage of ashes mixed with it; and in many cases the natives purposely mix more ashes to increase its bulk for sale. This lime is mixed with an equal quantity of soorkee, or pounded brickbats, so that the mortar is hardly fit for any building purpose, as it barely contains 15 per cent. of carbonate of lime. The failure of canal and other Government works in India has undoubtedly been to a great extent due to the use of mortar of this description.

As there was an abundant supply of this calcareous clay within 6 miles of the works, while the only other suitable lime was the Hill limestone, which was of first-rate quality, but at a distance of 60 miles or 70 miles; and as one half of this distance was through the hills, where camels only could be used for transport, thus nearly doubling the cost, it became a matter for serious consideration whether the calcareous clay could be employed. The following is an analysis of the clay, by Professor Murray Thomson, of the Government Engineering College, Roorkee:—

Moisture	1·44
Organic matter and moisture	1·27
Silicious matter and clay	49·80
Carbonate of lime	37·01
Carbonate of magnesia	2·79
Oxide of iron and alumina	7·69
	100·00

The Author determined to burn it in the same manner as was

done at the brickfields, which eventually turned out most successful. The marl, while soft, was roughly moulded into bricks. These were stacked to dry for three or four days, and were afterwards burnt with wood in kilns (built of sun-dried bricks made of clay), for fifty or sixty hours, according to the quality of the firewood, and the state of the weather. The flues were then closed with bricks and mud, and so allowed to remain for two or three days. On the kiln being opened, the lime bricks were unloaded almost in a whole state, were ground under stones, screened, and carried to the works pure and free from ash or dirt. The mortar was made from one part of ground lime, and one part of clear, sharp sand, excavated from the wells of the pier foundations about 15 feet below the bed of the river in the dry season.

This mortar was used in all the well foundations of the bridge up to the level of low water. It was tested in one of the wells, where part of the brickwork was taken down, after having been built six or eight months, and having been under water during the floods in the rainy season. As a proof of the quality of the mortar, it may be stated that it was easier to break the work as a mass than to separate it at the joints, or beds. Above the level of low water the mortar was composed of white hill lime, and soorkee, or crushed brickbats, in equal proportions, as it was found that the lime from the calcareous clay lost the greater part of its cohesion when used in work exposed to the vicissitudes of the atmosphere—whether this arose from the frequent changes from dryness to humidity, or from heat to cold, was not ascertained. This occurs with many of the Indian limes, as noticed particularly by Colonel Smith, in notes to his translation of M. Vicat's work on Limes and Cements.[1]

The well sinking for the foundations of the piers and the abutments was completed in little more than two years, which, without deducting any time for building up the brickwork, or for that unavoidably lost by the rise in the river during rains, gives an average rate of 159 feet per month, or in all, 3,800 feet. The time occupied in building the steining of the wells, erecting, taking down, and re-erecting scaffolding and staging for the sand pump, weighting the wells, &c., was equal to that employed in sinking. This would give a little over 300 feet per month, which may be safely taken as an estimate of the average rate of sinking. If cast-iron cylinders had been used, the sinking could have been performed more rapidly, on account of the portions of the cylinders being more easily put together, and owing to the slight bearing surface exposed by the thickness of the iron, compared with the breadth of the brickwork in the walls of the well. The superficial area of bearing surface would be in the case of an iron cylinder 18 feet, and in that

[1] *Vide*, "A practical and scientific treatise on calcareous mortars and cements, &c. By J. L. Vicat. Translated by Capt. J. T. Smith, M.E., F.R.S." 8vo. Lond., 1837. P. 213.

of a brick well 87 feet: the resistance by friction on the outside of both being the same. The total weight of the foundations and of the iron girder superstructure on each well was 420 tons, and the area of the bottom of each well being about 117 feet, the weight was less than 4 tons per square foot. This calculation is based upon an experiment made at the Jumna Bridge, Allahabad, where it was found that on a well with 42 feet of water round it, and weighted up to 10 tons per square foot, it did not sink any deeper, although the weight was left on for some months.

The novelty in the sinking of the wells of the bridge on the Delhi railway was in the use of the Sand Pump (Plate 16, Fig. 4). This consists of a wrought-iron cylinder A, having a pump E riveted to it at the top by an angle iron *e*. In this cylinder is a piston F fitting loosely, having a play of about $\frac{1}{8}$ inch all round. It is made of lead, and is pierced with small holes, to allow of the escape of the water as it descends, and on the top it has a flap of leather, or of india-rubber. It is protected by plates of iron, $\frac{1}{8}$ inch thick, at the top and bottom, and on the sides by an iron ring $\frac{1}{4}$ inch thick. The piston rod passes through a guide G, and terminates in an eye H at the upper end, to which a chain is attached to work it. The bottom B of the cylinder is moveable, and an upright suction-pipe C is riveted to it in the centre. This pipe projects outwards for a distance equal to its own diameter, and inwards nearly to the top of the cylinder. The moveable bottom is supported by the cramps *b*, turning loosely in the lugs of four stiffening pieces D, riveted to the sides of the cylinder, the cramps being tightened up by the cotters *b'*. At the top are eyes for lifting and lowering the whole apparatus by the slings S. In the cover of the cylinder are twenty four holes *a'*, with hinged india-rubber flaps, to admit of the escape of the water as the sand fills the cylinder; and a large hole, *a*, is cut out of the centre, to allow the pump to work.

The mode adopted for working the Sand Pump was as follows: A pair of sheer legs was fixed on the top of the well, and held in position by guy ropes; at the apex, or where the legs were joined, a chain was firmly fixed, holding in position a snatch block, through which the chain passed for lowering and lifting the whole machine. Two beams were placed on the top of the well, with rails forming a road for the trollies (which carried the Sand Pump) to run upon, two of them being used at each well. On commencing work, one trolly was brought over the centre of the well, and the pump lifted clear of the trolly, which was run to one side. The pump was then lowered to the bottom, when the chain attached to the piston rod was worked up and down, by men with ropes attached to the end of the chain, in a similar manner to a ringing engine. In this way water was first drawn through the upright pipe, followed by sand or other material, which fell over the pipe into the cylinder. This

operation was continued till the cylinder was quite full, which was known by the piston working stiffly, when the machine was raised to the surface. An empty trolly was then brought over the centre of the well, and the Sand Pump lowered down on to it, the cotters were driven back, and the cramps turned rather more than a quarter turn, which released their hold on the moveable bottom. The cylinder was next raised, leaving the bottom with a column of sand resting on the trolly, which was drawn to one side, and another trolly, with a cylinder bottom cleared of its column of sand, was brought under the sheer legs, and the cylinder lowered on to it and fastened with the cramps and cotters. The whole was then raised a few inches, the trolly removed back again, the Sand Pump lowered to the bottom of the well, and the same process repeated, so that no time was lost, as while the men were working at the pump down the well, the men at the top were clearing off the material brought up on the moveable bottom of the cylinder. The number of men employed at each well was fourteen; nine working the chain attached to the piston of the pump, two on the top of the well attending to the trollies and clearing away the stuff brought up by the pump, one in charge of a steam hoist, one breaking firewood, and an overseer.

The average rate of sinking, including contingencies, was about 6 feet in eight hours. This rate is extraordinary when compared with the old system of the jham and diver, and will, it is believed, materially reduce the expense of bridge-work in India, as regards the outlay upon labour in carrying out the work. The time also in which the work can be performed will be diminished. This is of the utmost importance from the working season in the beds of the rivers being so short, owing to the floods. If the low-water work cannot be performed before the commencement of the rains, another year goes by before the work can be completed, as nothing can be done during the rains, and till the rivers fall to something like their dry season level, and then a great deal of time is consumed in removing the silt and sand deposited over the site of works by the river.

The Author has endeavoured to describe the nature of the foundations, and the method adopted in their construction. He will now touch lightly upon the manner in which the superstructure was carried out. Fig. 5 is a section of the bed of the river taken in November, 1865, when preparations were being made for setting the curbs of the wells for the foundations of the piers. It also shows the level of ordinary low water and of the highest flood experienced during the construction of the bridge. Fig. 6 is an elevation of one of the abutments and a portion of a girder, with a plan at low-water level of the abutment with wing walls and counterforts. The wing walls of both abutments were carried well inland on the up-stream

side, to prevent the river from scouring into the railway embankment during high floods. The top of the wells was fixed at low-water level, after which the work was solidly bonded through, forming the pier. Up to low-water level the core of the well was filled with concrete, and on the top of this was built a series of stepped courses, forming a conical centre or a kind of stepped groined arch, upon which the upper portion of the brickwork was built. Six round bolts K, $1\frac{1}{4}$ inch in diameter, two of which are shown, were secured to the iron curb, and were carried up to about 6 feet above low water, at which level they passed through a concentric ring of flat iron, 6 inches broad and $\frac{3}{8}$ of an inch thick, and were firmly fixed with screwed nuts. There were three of these segmental rings in each well, at about every 15 feet in height. The brickwork was continued up to within 4 feet of the under-side of the girder, at which level the holding-down bolts C, of the bed-plates, which were 4 feet long and $1\frac{1}{2}$ inch diameter, were fixed with washers 6 inches square, Figs. 7 and 9. Fig. 7 shows enlarged details of the bed-plates, &c. Upon the top of the masonry of the pier thicknesses of felt S were laid to the depth of $\frac{1}{2}$ an inch. The wrought-iron plates A, 9 feet long by 3 feet 6 inches broad and 1 inch thick, were then placed upon this felt, and the cast-iron bed-plates B upon the top of the wrought-iron plates; and at the moveable end, where the girder E slides upon the rollers C, the plates were fastened together with the bolts P. At the fixed end the girder E simply rests upon the wrought-iron plate A, which was bedded upon the felt S.

The girders, which were on the single-lattice principle, were riveted together near the site of the bridge. They were then raised on to heavy low trollies, carried on a railway to where they were required, and lifted, by two powerful Wellington travelling cranes, clear of the tops of the piers, and lowered into position. Fig. 8 shows a half elevation and section of the girder. C is the end box, and A and B the top and bottom boxes, with the struts and ties connecting them. In the cross section, F shows the frames for joining the two girders together. There are six of these frames in each span, besides a rectangular frame with diagonal bracings at each end, riveted to the end boxes C.

The travellers were also used in lifting the pieces of girder into position for erection. It took eight days to erect and rivet each girder, and about one hour to lift it on to the trollies, carry it about 200 yards, and raise it into position on the top of the pier. The cantilevers E, Fig. 8, were riveted to the girders when in position. They were for carrying a footpath on each side, which was protected with a light wrought-iron railing.

The last girder of the bridge was put into place in July, 1868, and the first train ran over on the 16th October, 1868, when the

deflection and lateral oscillation were very small. The line is now open for traffic.

In this country various methods are adopted for sinking cylinders, suited to the different soils that have to be gone through. At the new bridge over the Clyde, at Glasgow, which is now being built from the designs of the Engineers, Messrs. Bell and Miller (MM. Inst. C.E.), a machine, on the dredger principle, was invented and tried by the contractors, Messrs. Hanna, Donald, and Wilson, of Paisley. It acted very well so long as no accident occurred; but if anything happened to any of the principal parts of the machine, then a serious delay took place in raising the whole machine and repairing it, and, of course, during that time the work was at a standstill. Another ingenious machine, which forms the subject of a separate Paper, invented by Mr. Milroy, one of the contractors for the construction of the Glasgow Union Railway, was used in sinking the cast-iron cylinders for the foundations of the piers of the bridge over the Clyde for that railway.

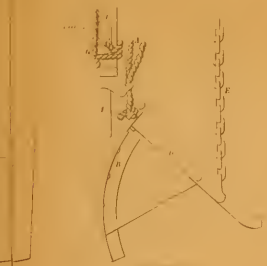
On considering the different plans, the Author is inclined most favourably to the Sand Pump of Mr. Howard Kennard, (Assoc. Inst. C.E.,) as from its simplicity it is peculiarly adapted for India, and for other localities where skilled labour cannot readily be procured. All that is required for the excavating part is a pump and a pair of sheer-legs; no staging, guides, or other preparations; and if anything does go wrong, the pump has only to be changed, which does not occupy more than an hour or two, and the cost is very small—about twenty-five pounds. The pump, as sent from England, was much improved in India, when used at the various bridges on the Delhi Railway, for which line Messrs. Brassey, Wythes, and Henfrey were the contractors. The pump had originally doors on the opposite sides of the cylinder, for removing the sand, &c. This proved to be a tedious operation, and caused great waste of time. Mr. J. C. Marillier (Assoc. Inst. C.E.,) suggested a pump without the doors, and in their place a moveable bottom, with a suction-pipe riveted to it. This saved a pump, as one pump with two moveable bottoms did the same amount of work as two pumps with side doors, and in less than half the time. The Author found it also saved time to have cotters in place of screwed nuts for clamping the bottom of the pump, and that it was advisable to widen the suction-pipe at the lower end, as shown in Fig. 4. The funnel end of the pipe steadied the pump, and allowed the sand, &c., to enter the pipe more freely. Mr. Charles Geneste, who was in charge of the Sutlej bridge works, adapted the pump for piercing clay, which he describes as follows:[1]—"On the lower part of the

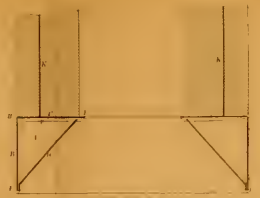
[1] *Vide* Professional Papers on Indian Engineering. Vol. iv., p. 255.

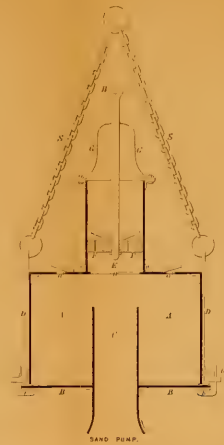
moveable bottom, radiating cutters have been fixed, made of plate iron $\frac{1}{2}$ inch thick, sharpened and steeled at the edge: these are about 9 inches deep. When anything hard is met with, the pump is lifted about 4 feet, and let fall again several times, and by this means the clay, kunkur, or whatever it may be, is generally broken up, and can easily be drawn into the pump. This last alteration has converted the Sand Pump into a clay-pump, and has enabled all the piers to be sunk 2 feet into the solid clay." With the attention that is given to cylinder-sinking by engineers, it is most probable that the system of wells or cylinders for foundations will be greatly extended, as in many instances they will be found the most suitable and economical for quay walls, for aprons to wet and graving-docks, for engine-seats, and many other works.

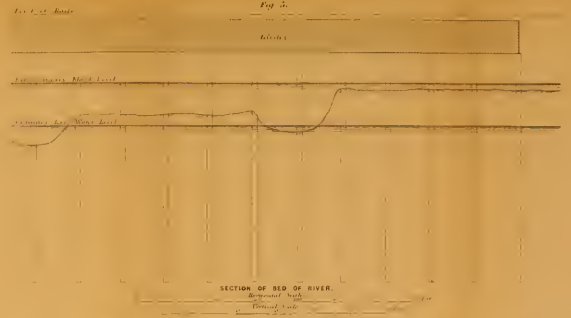
The communication is accompanied by a series of diagrams, from which Plate 16 has been compiled.

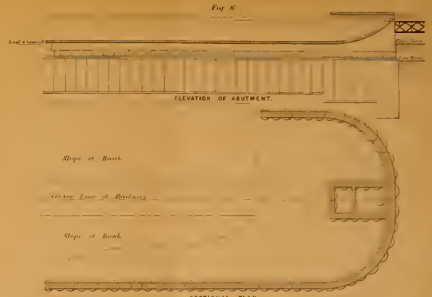
NATIVE JHAM


JHAM


CURB AND BRICK CYLINDER


SAND PUMP.

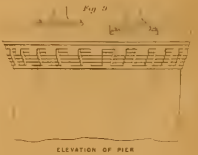

SECTION OF BED OF RIVER.


ELEVATION OF ABUTMENT.

SECTIONAL PLAN.

PLAN OF BED PLATES

GIRDER.


ELEVATION OF PIER

No. 1,228.—"Description of Apparatus for Excavating under water, and for Sinking Cylinders." By JOHN MILROY, Assoc. Inst. C.E.

To those acquainted with the various means which have been devised for the purpose of sinking cylinders, it must be well known that one of the chief difficulties, especially in sandy and all light and wet soils, is caused by the water. The great desideratum hitherto has been some method of excavating the earth to any depth required, without at the same time having to take the water out, and to keep it out during the course of the operations. The machine invented by the Author of this Paper seems to possess the advantage desired.

The method suggested itself, and an opportunity of testing it was first obtained, on Messrs. Brassey and Co. undertaking the works of the Glasgow (City) Union Railway, for which Mr. Fowler, (Past President Inst. C.E.,) and Mr. J. F. Blair, (M. Inst. C.E.,) are the engineers. This railway crosses the Clyde in the centre of the city of Glasgow by a lattice-girder bridge 375 feet in length, standing, in addition to the abutments, on six double stone piers founded on cylinders. There are five river spans, each 75 feet in the clear, and two land spans, each 65 feet in the clear. The bed of the river at the point of crossing is a layer of running sand 80 feet thick, resting on a stratum of hard material. The rise of the tide varies from 5 feet to 8 feet 6 inches.

In consequence of the nature of the foundation, the engineers decided on using cylinders; and for the sake of securing the utmost solidity, determined that, in the stream at least, they should be sunk right through the running sand down to the solid stratum. On account of the nature and great depth of the material to be penetrated, it was thought that it would not be possible to do the work except by the pneumatic process, and considerable anxiety was felt as to the issue. Under these circumstances it was determined to try a plan which had suggested itself as feasible, and which it is the purpose of this Paper to describe. Objection was at first taken to its adoption on the ground that, even if the machine succeeded as an excavator, the fine sand composing the bed of the river would run in as fast as it was taken out. It seemed to the Author, however, that running sand depends for its locomotive power on the water which it contains, or, rather, in which it is contained, and that there would be no action from the outside inwards so long as the cylinder was kept full of water.

The new method of sinking was accordingly at once put to the test. The first proceeding after the erection of the staging was to drive four piles, which are of use, both to determine the position of the cylinder, and to secure, at least for the first few feet, its perpendicular subsidence. This is an indispensable precaution if the load necessary to force the cylinders into the ground is to be placed on the top, but it is not so much depended on in the new method of weighting which was then introduced, it is believed, for the first time. In order to explain this, it will be of advantage to begin by describing the adjustment of the weights.

The practical question with regard to the mode of weighting the cylinder seems to be,—How are the weights to be disposed, so as to distribute the load as much as possible throughout the cylinder, and to secure gravitation acting with certainty in one direction, while at the same time it shall be possible to carry on the excavation without hindrance or confusion?

In order to effect these objects, each length of the cylinder, which was 6 feet 6 inches in height, and 8 feet 4 inches in diameter, was cast with brackets 6 inches long on the internal lower flange. In addition, the weights were cast in segments, 1 foot high and 6 inches thick, so as to fit into the concave side of the cylinder, and rest on the bracket. Each length of cylinder was weighted by lowering down the weights with a crane, after it had been placed in position, and properly fastened to the one below it. The only lengths which were not loaded were the first or lowest pair, which were left free to sink into the ground, and to receive a bed of concrete previous to the water being taken out. The load of weights deposited in each length of cylinder amounted to $10\frac{1}{2}$ tons, laid in five rings, one above another; and this quantity was found sufficient to overcome the lateral friction.

According to this system of loading, the weights when in their places cause no further trouble; and, as they lie in a circle, the outer circumference of which is bounded by the cylinder, they require no support, the pieces mutually preventing each other from falling in. They take up no room, and, as they are not in the way, the excavation can be carried on without hindrance or interruption. By this system also the pressure downwards is equally distributed throughout the entire length of the cylinder; and thus, as the cylinder is always full of water, any risk of divergence from the perpendicular is almost entirely removed. All these advantages seemed amply to compensate for the extra expense of having the weights cast; and it may be doubted whether any of the other methods of loading with their attendant risks would have been more economical, even had they been equally convenient and successful.

The excavating apparatus, commonly called the 'Excavator,'

devised for the purpose of excavating the interior of the cylinder, may be described as follows:

It consists of a horizontal frame of iron, with an outside rim 9 inches in height, to which radiate, like the spokes of a wheel, T-irons from a small cast-iron ring in the centre. To the bottom of the outside rim are hinged eight heavy iron spades, which, when drawn in, fit closely into each other, with their points pressing against the ring in the centre of the frame. The hinges of the spades are so constructed as to prevent them from turning back beyond the perpendicular, when allowed to fall open, or when being forced into the ground. The whole apparatus is strongly made, and it forms, when closed, a nearly water-tight tray.

When the machine is descending, the spades are let down in a nearly vertical position into the ground, where they are held in a way afterwards to be described. The spades are then drawn by a set of chains through the ground up to the frame, which, with the earth contained in it, is raised to the surface.

The various movements are effected by two sets of chains attached to a main or hoisting chain, A (Plate 17), which passes over a pulley aloft on to the barrel of a double-acting 12 H. P. engine. The first set of chains, all of equal length, are fastened at one end to the rim of the Excavator; and at the other, after uniting into a length of single chain, to a clutch or monkey-hook C, a few feet up the main or hoisting chain. These are for the purpose of lowering the Excavator; and when it hangs by them, the spades fall open from their own weight as shown in Fig. 1. The second set, D, consists of eight chains, all of equal length, each fastened at one end to the inside of a spade, and at the other to the end of the main chain. These are for drawing in the spades and raising the whole machine.

The two sets of chains are worked thus: Before lowering the Excavator the chains B are hooked up to the extent of their length of single chain on the monkey-hook C, by disengaging which by means of a rope, they are allowed to fall slack as soon as the spades are felt to be in the ground. When this takes place, and the engine begins to pull in the main chain, the chains D, being now shorter than the other set, are brought into play, drag the spades through the ground, and raise the whole to the landing-stage. A lorry is then pushed in underneath for the Excavator to rest on; the chains B are hooked up, the machine is raised a little, when the spades fall open, and the material is discharged into the lorry.

It is still necessary to describe the method employed for forcing the spades into the ground. To effect this object, two leaders are lowered down on opposite sides of the interior of the cylinder. These are two pieces of timber, which are kept at their proper

distance from each other by being fastened at their lower ends to a strong iron hoop, and at their upper ends to the cylinder itself. As the depth increases, additional lengths of timber are added, and perhaps one or two intermediate hoops are inserted. The leaders have no connection with the cylinder except at the top, and accordingly can be easily removed. Each leader is made of two pieces of timber, 6 inches by 4 inches, fastened together, between which is fixed at either end a pulley. Corresponding to these, there will be observed in Fig. 1, on opposite sides of the Excavator, a separate chain F, fastened to the top of an upright T-iron, or arm. This chain passes down the cylinder, under the lower and over the upper pulley of a leader, and is wound round the large axle of a capstan, or drum on the landing-stage. The chain is calculated, when tightened, to force the spades into the ground, and to keep the machine down whilst they are being drawn in. The drum employed to give leverage in raising and lowering the chain is put in motion by two men unwinding a rope, or suffering a rope to wind itself round it. There are two of these drums opposite each other, corresponding to the two leaders and the two dragging-down chains.

The mode of working the arrangement just described is as follows: When the Excavator is being lowered, the men pull in the ropes in order to keep the chains taut; when it reaches the ground, they drag at the ropes and throw their weight on the capstans, in order to force the spades in; they hold on while the spades full of earth are being dragged in by the engine to the frame; and as soon as they feel the machine rising, they allow the ropes to rewind themselves on the drums.

It will, of course, be understood that the form of Excavator delineated in Plate 17 is not the only one which might be adopted. Its shape may be modified to suit the particular excavation required, and the number of spades may be increased or diminished. Pulleys fastened to the bottom of the cylinder may be substituted for leaders. By another arrangement, any means for holding down the Excavator may be entirely dispensed with, though with the result of greatly diminishing the amount of earth brought up. The contrivance for effecting the opening and shutting of the spades is capable of several modifications. The spades themselves may be altered in form. For instance, in the first Excavator the spades were made with sides fitting closely into the interstices of the frame, with a view to prevent the sand from being washed out. But subsequently the sides were removed, as they were found to interfere with the penetrating power of the spades. Lastly, in working in a gravelly soil, a pronged spade, like a man's hand, might be used.

In order to enable an opinion to be formed of the capa-

bilities of the Excavator, it may be well to mention the following characteristics of its working. The progress of the excavation, and the corresponding subsidence of the cylinder, reached (inclusive of the time employed in adding and fastening fresh lengths of cylinder, putting in weights, adjusting leaders, &c.), from about 12 feet to 20 feet per day of ten hours. When there has been little interruption for any of the above purposes, it has reached 25 feet in ten hours.

When the men at the Clyde Bridge had become accustomed to the duties required of them, it was determined to devote as far as possible a whole working day to the cylinder-sinking, with a view to ascertain accurately the capabilities of the machine. On the occasion referred to the men began work at 6 A.M., and stopped at 6 P.M., with two intervals of an hour each during that time for meals. The following was the result obtained :—

Depth of cylinder sunk	25 feet.
Time employed in sinking and excavating alone	6 hrs. 44 min.
Time employed in adding two lengths of cylinder, putting in weights, caulking, arranging leaders, &c.	3 hrs. 16 min.
Total length of working day	10 hours.
Average depth from the landing-stage to the bottom of the cylinder during the day's excavation	66 ft. 6 in.
Average depth of water during ditto	50 feet.
Number of lifts of the Excavator	119
Average time of each lift	3 min. 23 sec.
Average quantity of sand brought up at each lift	21 cubic feet.
The total quantity of sand brought up during the above 6 hrs. 44 min. was found on measurement to be	70 cubic yards.

The last-mentioned quantity falls short of the actual quantity excavated, as much of the sand, in being discharged from the lorry, was washed away into the river. In fact, the above results were obtained with an Excavator 5 feet in diameter, which brought up at each lift about three-quarters of a cubic yard of earth. Twelve men in all were employed: One engineer, one stoker, six men working the drums, three attending to the landing and discharging of the Excavator, and one wheeling away the sand discharged.

It may further be mentioned that the machine was as effective at 100 feet (that being the length of cylinder reached when the hard foundation was struck) as at 10 feet, bringing up quite as much sand. The only difference at the greater depth was the longer time occupied by each lift, and the necessity of placing an extra man or two at each drum. The suitability of this apparatus for excavating at great depths is of considerable importance, and entitles it to the consideration of mining engineers, as well as of coal and iron proprietors and lessees, whose minerals underlie a stratum of sand or other light material charged with water.

It was observed, that when the tide was out, and a heavy

column of water was in the cylinder, much higher in level than the stream outside, less earth was brought up in the spades. The greatest loads were raised, and the cylinder sank most freely, when the tide was coming in. Accordingly, to meet the fall of the tide, and to relieve the pressure on the ground inside, nothing further was necessary than to detach the Excavator from the main chain, and, hooking on a large barrel, to draw a few barrels of water. But it may be well to mention, that it is necessary to be cautious in making use of the barrel, in order that too great a preponderance may not be established in favour of the water outside, the result of which would be an upheaval of the earth inside. Such an event is to be avoided, as it not only increases the amount of material to be excavated, but has a tendency to jam the cylinder. Accordingly, when there is little earth in the cylinder, it is best to cease drawing as soon as it begins to sink.

In conclusion, the advantages of the Excavating Apparatus, which is now being used on other works in sinking through clay, sand, and other materials, may be summed up as follows:—

1st. It is perfectly independent of water, which is allowed to remain in the pit or cylinder until the excavation is completed.

2nd. It can be used, and is equally effective, at any depth without sensible difference in the cost of working.

3rd. Its rate both of sinking and of excavating is higher than has yet been attained by any other method.

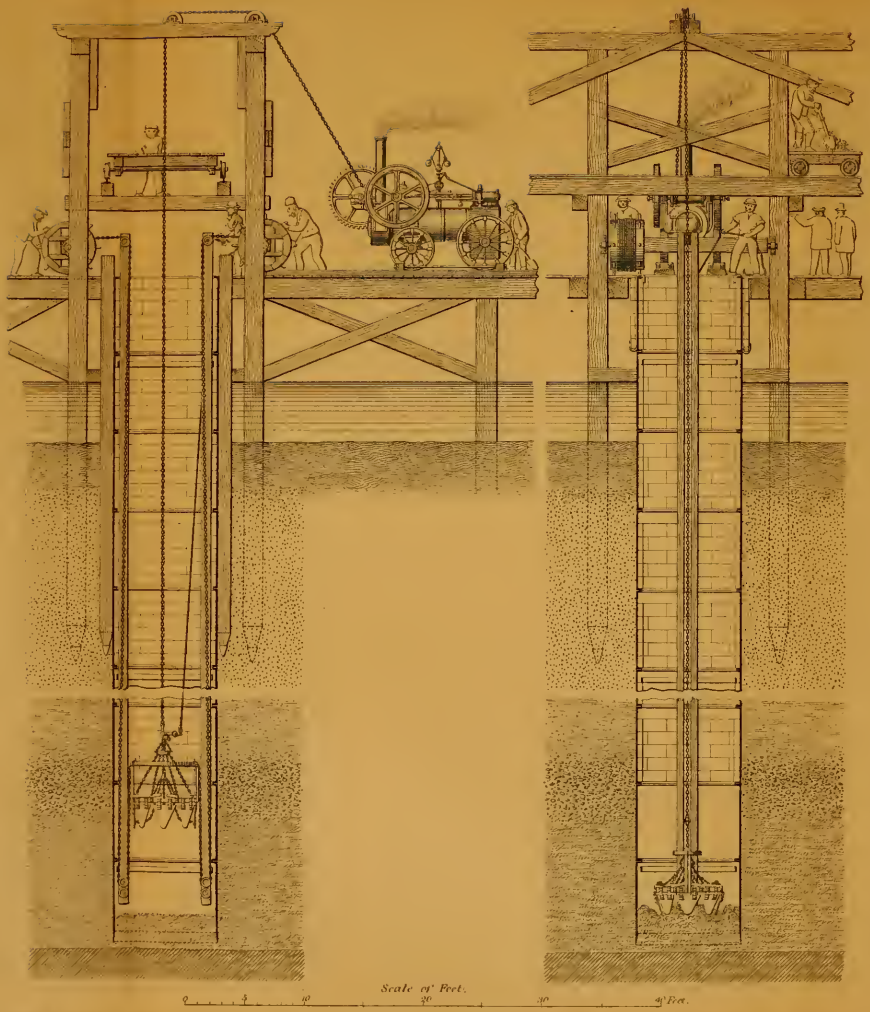
4th. Its use is not attended with any danger. It is also exceedingly simple, easily repaired, and not liable to get out of order.

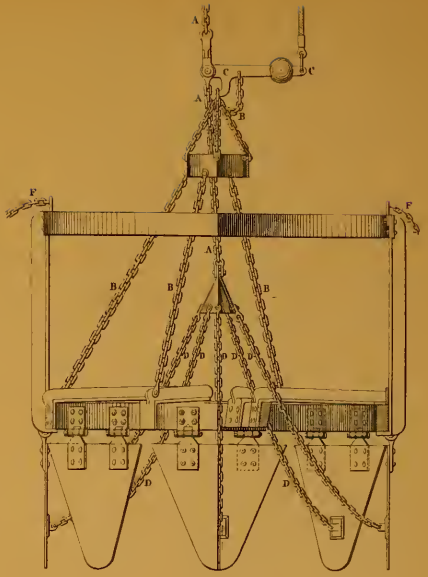
5th. Its action is always in the same perpendicular line; and thus, as the cylinders are weighted throughout their entire length and are full of water, no divergence of a cylinder from the vertical during the course of the excavation ever takes place.

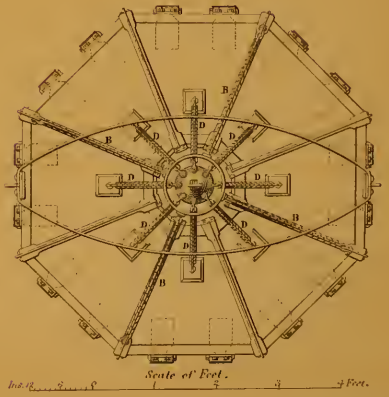
6th. The expense attending its working is comparatively trifling, as skilled workmen are not required.

The communication is accompanied by one drawing, from which Plate 17 has been compiled.

EXCAVATING APPARATUS.







Mr. H. J. Kennard said, he had just completed a contract for a bridge in Ireland, where both these machines had been used, and where he found the Excavator of Mr. Milroy more effective than the Sand Pump. He was of opinion that in sinking cylinders, it was important the person in charge of the work should not be prejudiced in favour of one system, as he had then invariably found great expense was the result.

He explained the working of the Sand Pump by means of a model. The pump was made of an ordinary cylinder of any diameter, with the piston cylinder projecting slightly below the upper edge of the box. The pump might now be supposed to be standing at the bottom of the cylinder, or on the material to be excavated. When that was the case, the only action necessary to bring the material to the inside of the box was that of the raising and falling of the piston. When the piston was raised one of two things took place: either a vacuum was formed in the box, or the material rushed in in a volume and filled the box. The sand was thus drawn into the box, and, with the down motion of the weighted piston, the water was expelled from the valves. When the box was filled, the machine was raised, as explained in Mr. Bell's Paper. To empty it, the collars were knocked out, and it was lifted off the moveable bottom of the machine and placed on to another bottom, two moveable bottoms being used to each machine, to save time in clearing out the sand. He was indebted to those who had used the machine in India for this suggestion, as it was found quicker to empty the pump in that manner than through the holes in the side, originally designed for this purpose. The main advantage of this system consisted, he thought, in its extreme simplicity. The pump required no gearing, or mechanism of any kind, and indeed nothing more than a steam crab, or simple windlass, to raise the machine. The speed at which the box was filled depended upon the nature of the soil in which the excavation took place. He had known the box to be filled in three minutes, containing $1\frac{1}{2}$ cubic yard of soil. The rate at which the work was done depended upon the apparatus for raising and lowering the machine; if the apparatus was good, the work would be done quickly; if bad, it would be slower. He thought the amount of work performed by the Sand Pump in India was very satisfactory. It exceeded anything he had observed in his own experience, and he was not previously aware that it had ever done so much work as that of sinking a cylinder, 14 feet in diameter, 6 feet in a day of ten hours. This could only have been accomplished by the machine being both well managed and well attended to.

The principle of working Mr. Milroy's machine was almost identical; and in the case of the bridge in Ireland, to which he had alluded, he was bound to say it worked more satisfactorily than the

pump. The reason was that the stratum was fine silt mixed with clay of a peculiar character, such as he had never met with anywhere else. The moment the pump was at the bottom and the piston was raised, instead of sucking the sand into the box, as might be supposed would be the effect with common sand, it only sucked out a hole, because there was a sufficient amount of clay mixed with the sand to prevent the water permeating through it regularly. The hole became, as it were, a pipe, and the effect of raising the piston after that was simply pumping water without sand. It was about that time he heard of Mr. Milroy's machine, and he resolved to obtain information about it. This was furnished by a foreman who was sent with the machine by Mr. Milroy. In saying that machine worked very satisfactorily, he ought perhaps to mention, that the soil operated upon was so peculiar and tenacious that no machine whatever could work well in it; that was to say, do the work cheaply. He was, however, perfectly satisfied with the machine and of its great value. In explanation of the model of Mr. Milroy's Excavator, Mr. Kennard showed how, when a load of material had been discharged, the machine was lowered, the spades were forced into the soil, so as to excavate it, then pulled together to form the bottom of the tray in which the material was lifted to the surface, and again discharged into the truck placed ready to receive it. He believed that the Paper of Mr. Milroy fairly stated the work done by his machine at Glasgow. That was a favourable place for its application, and he thought, from all he had heard, the results were not overstated. The machinery was beautifully arranged, and, being in the hands of an experienced foreman, the work was well done. Although, in the case of the bridge in Ireland, it did not answer completely to his satisfaction, from the cause stated, he desired to say that it was in his opinion a valuable machine. In many cases he thought it would be found quite as good as the Sand Pump, and in some instances even better. He believed it would be found to be efficient where the ground was loose and the stratum was not a stiff clay, but a certain amount of skilled labour was required to fit the gearing ready for action. He understood some cylinders were about to be sunk in the neighbourhood of London by Mr. Milroy's Excavator, and Mr. Kennard would venture to say, that if any member of the Institution wished to see the working of the machine, every information would be afforded.

Having had considerable experience in cylinder sinking—he believed he had sunk 20,000 tons of iron cylinders — he was of opinion that the question to be decided was, what machine to use under the particular circumstances in which the work was found. If the compressed air system was adopted where the Sand Pump or the Milroy Excavator would do the work, three times the money

would be spent. If, on the other hand, attempts were made to use these machines where compressed air was necessary, then, after a good deal of work had been done, that system must be reverted to. He considered that engineers generally were greatly indebted to the pneumatic apparatus, which in all cases rendered the sinking of cylinders a certainty, as it enabled the work to be prosecuted as on dry ground. He considered Mr. Hughes' modifications an improvement upon Dr. Potts' original suggestion; and it was undoubtedly that system which first gave him the idea of the Sand Pump, which was an adaptation of the vacuum principle by a different and simpler process. He looked upon this pump as being peculiarly suited for operations in India, where the foundations of almost all structures were constructed on brick wells. In such cases he apprehended the Excavator would not be applicable, for the want of sufficient room to work in.

Mr. Bazalgette remarked that the sinking of cylinders, for various purposes of construction, was greatly on the increase in this country, and was adopted with manifest advantage. It was therefore of importance to obtain the results of practical experience, as to the best mode of sinking cylinders through different kinds of soil. He had used the pneumatic, the spoon and bag, divers, and other methods, and it was desirable that those who had had experience in these works should put that experience on record in a practical shape. He should be glad to learn what was the cost of sinking the cylinders and the rate of progress, under the conditions mentioned in Mr. Bell's Paper, as a means whereby a comparison could be made of the cost of sinking cylinders in different soils, as he considered the discussion of those points would be very beneficial. In throwing out this suggestion, he should be prepared to add his meed of experience to that of others, inasmuch as it was only by comparison that practical data could be arrived at, upon which to determine what plan should hereafter be adopted for sinking cylinders in different descriptions of soil, or other local variations of circumstances.

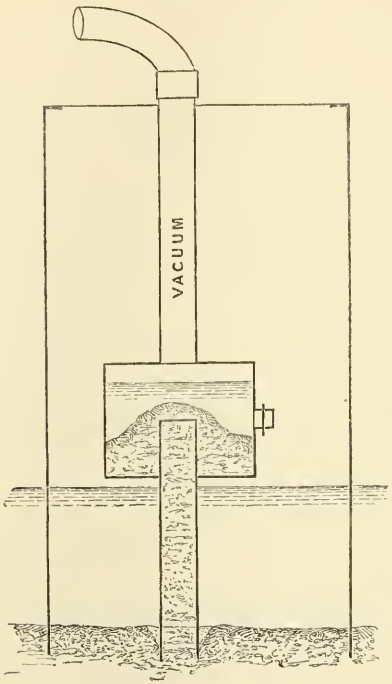
Mr. Joseph Phillips thought it would be difficult to give the cost at which any particular cylinder could be sunk to a given depth, inasmuch as the cost must necessarily vary with the nature of the work, the number of cylinders to be sunk, and other incidental contingencies. Again, the cost of labour in sinking cylinders would vary even with cylinders of the same diameter, from local circumstances requiring different modes of treatment. In all cases the mode of dealing with the cylinders must depend upon the experience and practical knowledge of those in charge, and also upon the progress made with the first cylinder sunk of any series. He had not seen either the Sand Pump or the Excavator in operation, but he knew from Mr. Kennard's ex-

perience on the Continent, as well as from communications he had received from India, the value of the Sand Pump for foundations which were peculiar to India, and other districts in which sand occurred in large quantities. He also believed Mr. Milroy's Excavator was useful for sinking through light soils, and possibly through light clay. Clays differed very much. In Holland a material was called clay which would not be so designated in this country. He did not think the Excavator would be able to work through the London clay, but he had no practical experience on that point. By both these methods of sinking cylinders, an equilibrium was assumed to be maintained between the water in the inside and on the outside of the cylinder. Wherever that could be done, it simplified matters very much, whatever means of sinking was adopted, whether by the spoon and bag, or by the dredger. He thought neither the Sand Pump nor Mr. Milroy's Excavator was applicable entirely to the principal works at present in course of execution in England and on the Continent, as the contract specifications generally required that the cylinders should be sunk so as to leave the bottom dry, and that the concrete should not be passed through water. This necessarily involved the use of the pneumatic apparatus, and opened up a question of importance, whether it was desirable to see the bottom and to put the concrete in dry. If the cylinder had to be drained and the concrete put in dry, the cylinder must be more strongly constructed, and the expense must be incurred of employing the pneumatic apparatus. Mr. Hawkshaw had adopted the plan of putting in the concrete through the water, which he believed was found to be equally good with concrete put in dry, and he had followed the same course in works of his own, where the water could not have been got out except at great expense.

Mr. E. A. Cowper said he had carried out Dr. Potts' system to a certain extent. In some cases he had employed a large vacuum chamber, pretty well exhausted, before the valve was opened to communicate with the pile: and he had sunk a pile as much as 5 feet, in a quarter of a minute, with one exhaustion of the chamber. Fig. 1 showed how Dr. Potts proposed, not only to exhaust the air out of the pile, but also to use the 'elephant's trunk,' the 'trunk' being used inside the pile, to suck up the material into a box, or receiver, so as to do away with the column of water in the pipe, acting as a resistance. The box was let down into the pile and raised the material by the draught or suction, or, more exactly speaking, by the pressure of the atmosphere forcing the water and material into the box. The high column was a column of air, and the only column of water that caused any resistance was from the surface of the water in the pile up to the inside of the box. When piles were sunk to a great

depth on Dr. Potts' plan, the column of water was objectionable, as there was then only the pressure of the atmosphere to make the material rush in; and if there was a considerable column of water inside the pile, the effective force was much reduced. He

Fig. 1.



was glad reference had been made to Dr. Potts' system, because he felt it was one which well deserved the notice of engineers. If it were desired to see the ground before the foundation was put in, it might be done in this way:—the excavation might proceed, with the water inside the cylinder, either on the Milroy, the Kennard, or the Potts' plan, till the proper depth was attained; and then, if it were wished to execute any work at the bottom, it could be done by means of a diving-bell, lowered inside the pile.

Mr. Milroy, jun., was much obliged to Mr. Kennard for the way in which he had spoken of the Excavator, particularly as that machine was to some extent in rivalry with the Sand Pump; at the same time there were one or two remarks to which he must take exception. The first was that skilled labour was required in

working the Excavator. He did not think that was the case, because it was easy, as at the Clyde Bridge, to teach ordinary labourers to work the drums properly in the course of a few hours, and the only skilled men required were the engine-man and the foreman: so that substantially it seemed no skilled labour was needed. As for the machine not being able to work in a brick cylinder, he did not understand how that could be, because it was only a question of adapting the size of the Excavator to the size of the cylinder. In fact it appeared to him that the Excavator would have the advantage over the Sand Pump in a brick cylinder, because the lower orifice of the Sand Pump worked only at the centre of the large circumference at the bottom, whereas the spades of the Excavator, by attacking nearly the whole area, went as nearly as possible to the outer circumference, and consequently would more effectually remove the sand which supported the brick cylinder. As to the Excavator not being able to sink through clay, he believed it had already done so, in the case of the New Ross Bridge, inasmuch as he understood the soil met with there was substantially clay. He was not in possession of such information as would enable him to say whether it would be equally effective in sinking through London clay. With regard to the alleged necessity of putting in the concrete dry, he understood that in the case of the Clyde Bridge it was successfully lowered before the water was taken out.

Mr. Imrie Bell wished to say, in reference to Mr. Bazalgette's remarks as to the cost of sinking cylinders, that he apprehended it would be about the same with both machines, so far as manual labour was concerned, to which would have to be added the percentage for engine power and plant; the Milroy Excavator requiring an engine of 12 H.P., and the Sand Pump one of 4 H.P. It was to be regretted that Mr. Milroy had not stated the entire time taken in sinking the whole of the cylinders of the piers of the Clyde Bridge, as the delays in altering and repairing the machine, in fixing the staging, &c., in well-sinking, generally took up an equal amount of time to that employed in the actual sinking. Mr. Milroy only stated that the cylinders were sunk at the rate of 12 feet per day, and that on one occasion they were sunk as much as 25 feet. The amount of work performed by the Excavator when all was going on well seemed to be remarkable; but notwithstanding all that had been said in its favour, it did not come up, in his opinion, to the Sand Pump, especially for India, where the simplicity of a machine would be the primary consideration. In quartz and limestone boulders, the Excavator would be sure to work at great disadvantage, even with the grape, or fork-shaped spades, which in many cases would be simply turned, or bent up. This had happened when he had used a pronged 'jham;'

the prongs coming upon the top of a boulder, were either broken or bent up, and a diver had to be sent down to loosen and bring up the large stones. Whereas the Pump brought them up through the pipe into the cylinder as easily as it would work in sand.

With regard to sinking wells in a line, as, for example, in the extension of wing-wall foundations, he found it advisable to sink them alternately, as they were less liable to get out of the perpendicular. In sinking a well, or cylinder, through sand under water, the sand for some distance round was in an agitated or boiling state; and it might be imagined, if two wells were sunk together in close proximity, that the ground at the point between the two cylinders would in all probability be the softest, from the agitation caused by the excavation in both cylinders proceeding at the same time. There would naturally therefore be a tendency to sink more rapidly at that point and to lean over; whereas when the sinking was carried on alternately, the cylinders were not affected to the same extent. The value of the difference in the level of the water outside and inside the cylinder had been noticed. He had frequently observed that, when wells 'hung,' or, in other words, when, on the stuff being excavated from beneath, the cylinders did not sink, on the water being lowered 5 feet or 6 feet by pumping, the well sunk at once a few feet. The cause of the well not sinking was probably owing to want of weight, the friction of a layer of some firmer strata than sand being greater than the weight of the cylinder, thereby holding it up. He considered this mode of sinking open to serious objections. In the first place the brickwork of the well must be severely shaken by such a sudden descent, and in the second place the well was very liable to get out of the perpendicular. The safest way was to keep the water at nearly the same level—if anything, rather lower on the inside—to produce a slight agitation from the pressure outside; but the nature of the strata and local considerations varied so much, that it was impossible to lay down any exact rules. He thought the cost of one work would be an uncertain guide for another under different circumstances.

Mr. Bramwell said these two Papers, though principally devoted to a description of two different modes of getting the material out of the inside of cylinder foundations, naturally opened up the question of cylinder foundations generally. Mr. Imrie Bell had alluded to the plan of making foundations in India by sinking brick wells. That plan had been known from time immemorial, as was stated in a Paper by Major (now Major-General) Goodwyn, R.E., read in 1842,[1] and in another Paper by Mr. Bruce, which was read in 1857.[2] So far, therefore, as regarded the sinking of cylinders of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 63.
[2] *Ibid.*, vol. xvi., p. 449.

some kind for foundations, it was a plan the origin of which was lost in remote times. In the case of the wells in India, the surface being open to the air, the water rose freely from the water-bearing strata, and the material was removed by an implement, either by men standing above the well, or by the employment of divers below the surface of the water, who worked only for a few seconds at a time, as they were without the aid of the modern diving-dress, or of any substitute for it. In the description of the Charing Cross Bridge, by Mr. Hayter,[1] where it would be remembered open-top cylinders were used, it was stated that the material was excavated by men in diving-dresses. The Indian wells and the Charing Cross Bridge had therefore this fact in common, the use of cylinder foundations and the removal from those cylinders of the material by an ordinary process of digging.

But in the Papers under discussion, the apparatus in both cases—that was, the Sand Pump of Mr. Kennard, and the Excavator with folding bottom of Mr. Milroy,—afforded a means of removing the material from the cylinders without the employment of manual labour under water. In considering this subject, he thought this important question arose; whether, if the cylinder was not heavily loaded, so as to follow down at a rate corresponding to that at which the material was removed, there was not great liability of a flow of material into the cylinder, even although there was the pressure of water inside; and thus the work would be constantly renewed, as other soil from the exterior came in under the cylinder and required removal. These were, in his judgment, fundamental objections to getting the stuff out through the cylinder, where that stuff was of an extremely moveable character; or if not objections, at all events were reasons for insisting upon the necessity of urging the cylinder downwards with the greatest possible energy while the digging was going on. It was clear that a preventive to the entrance into the cylinder of additional soil would be found in the employment of a means which should get rid of the earth already in the cylinder, not by removing that earth up through the middle of the cylinder, but by expelling it outwards under the bottom; and such a means was provided in that which he would, as a descriptive name, entitle hydraulic digging. About two years ago, through the kindness of Mr. Zerah Colburn, (M. Inst. C.E.,) he saw some photographs of an apparatus invented, as far as he knew—at all events in use—in California, by which hydraulic digging was carried out for ordinary purposes of surface digging in gold washing from the gravel. This was effected by a powerful jet from a very high head of water, which on being presented to the lower part of the face of a gravel bank

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 512.

undermined it, so that the upper part fell in. The pieces were then still further cut up by the application of the jet. That was hydraulic digging in its simplest form. Since then he had found a description of that mode of working in a book in the Library of the Institution.[1] That being an illustration of the powerful action of water, one could understand how, in sinking foundations where, as a rule, there was a superfluity of water, if it could be employed in the form of a current it might be used for the purposes of digging. Such a use of a current of water was brought under the notice of the Institution in the year 1847, in a discussion upon the Ventilation of Mines, in which the Rev. Dr. Buckland, then Dean of Westminster, took part, and in which he alluded to a recent French improvement in the digging of artesian wells.[2] The improvement consisted in the use of a hollow tamping tool, down which water was forced, causing a current to rise up round about the tool, by the strength of which current the debris of rock was got up to the surface. So efficient was this system, that stones 3 inches by $1\frac{1}{2}$ inch were brought up. Dr. Buckland did not give the name of the improver; but in a more recent Paper, by the late Mr. G. R. Burnell, "On Machinery employed in sinking Artesian Wells,"[3] M. Fauvelle was mentioned as the inventor, though the system was stated to be of Chinese origin; and it was added that, for the purpose of artesian wells, it was not found efficient at great depths. Of course those depths which would be shallow for artesian wells would be deep for bridge foundations; and therefore the fact of the system not having been thoroughly successful in deep artesian wells was by no means inconsistent with its being entirely efficacious for the purposes now under consideration.

Mr. Bramwell had mentioned these facts, because he wished to direct attention to the use of hydraulic digging, or water currents, in sinking cylinders. He believed the first person who used water currents for this purpose was Dr. Potts, who, in the case of small piles, carried out a direct connection with exhausting pumps, or, in the case of large piles, employed an exhausted receiver, to which a moveable pipe, called from its form an elephant's trunk, was attached, and by the exhaustion established a water current up this trunk. Thus, either by the direct connection with the air-pump, as in the case of the small piles, or by the elephant trunk plan, in that of the larger piles or cylinders, there was hydraulic digging below the edge of the cylinder, so enabling it to go down. Dr. Potts also obtained the assistance of the pressure of the air. On piles 1 foot in diameter, such a pressure would not exceed half

[1] *Vide* "La Vie Souterraine, etc." Par L. Simonin. 8vo. Paris, 1867; p. 497, fig. 147.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. vi., p. 195.

[3] *Ibid.*, vol xxii., p. 462.

a ton; but it was curious to notice, that the success of Dr. Potts' plan had been attributed to the fact of there being a great pressure of air on the top of the piles, the truth being that a current was established, and that thus hydraulic digging was effected.

With reference to the two processes of digging, one by drawing inwards, as proposed by Dr. Potts, and the other, hydraulic digging, by forcing outwards,—this difficulty occurred in regard to the former; the water coming in brought with it earth, which was originally exterior to the cylinder, and unless the cylinder were heavily weighted, so as to urge it down as rapidly as possible on the earth being moved below its edge, a large amount of earth was brought in without any progress being made in sinking the cylinder. There would thus be many more times the quantity of material to get out than there would be if a current could be established in the other manner, by forcing outwards. It might be objected, that in making a current outward, material was being forced into a place already full; whereas in drawing in, the material was drawn into an empty space. The answer to that objection was, that, as a rule, any soil which required cylinders to be forced through it was one into which cylinders could be introduced, and that was done by forcing the material away sideways; that being so, no impossibility was involved in the supposition of forcing the current outwards, and with it forcing the material. The system of outward currents had been applied by Mr. Brunlees (M. Inst. C.E.) in the sinking of the piles of the Morecambe Bay Viaducts,[1] and those of Southport Pier.[2] In these cases a pile 1 foot in diameter, having a disc on the end, and a close bottom, was caused to sink by sending down a 2-inch pipe a column of water, which, rushing under the disc, dispersed the soil, and left a vacant space into which the pile entered. That plan commended itself to his mind as the correct one; but it might be said it was not applicable to large cylinders. He was inclined to think otherwise. He proposed that there should be at the bottom of such a cylinder a massive cast-iron plate, so heavy that the pressure of water to be carried down below it should not tend to raise it, having regard to its own weight and the weight of water above it. The pipe down which the water was to be forced might be attached to that plate, which was independent of the cylinder; and the pipe, being carried up to the top, could be either fitted with a worm wheel, to keep it in a state of rotation, or could be maintained in a state of oscillation by means of hand spikes. In that way the disturbance of the soil might be effected. Mr. Brunlees had accomplished this by causing the whole pile to vibrate, so as to move the sand; but this plan of moving the whole cylinder was

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., p. 442.
[2] *Ibid.*, vol. xx., p. 292.

hardly applicable when the size of the cylinder became large, although Mr. Brunel had sunk cylinders in the bed of the river Wye by actual rotation, the cylinders being furnished with a screw. If, however, the massive bottom plate alone were rotated, hydraulic digging was obtained with an outward current in large cylinders. When the right depth was attained, the plate could be lifted through the flanges, and be used for other cylinders of the same size. In the case of the Rochester Bridge,[1] the cylinders when sunk were closed at the top, and compressed air was put into them. By that means the bottom was kept dry, and exposed to the action of the workmen. In the case of the Saltash Bridge,[2] instead of the whole cylinder being filled with compressed air, the bottom part alone was filled; but not being compressed to the full head of water, some water got in, and had to be removed by pumping. At the Kehl Bridge a similar plan to that adopted at the Rochester Bridge was proposed, and a tube was introduced which projected beneath the bottom of the caisson in which worked a dredging-machine, the bottom being sealed by the water, and the material going up by the dredger. In the course of this discussion Mr. Cowper had suggested that if it were required to see the bottom of the cylinder, that wish could be gratified by going down in a diving-bell. That seemed to him to be a very practical suggestion. He would add, that if the soil to be dealt with was not sufficiently moveable to be operated upon by an outgoing or an incoming current, but which, from its being a mere crust, it might be necessary to go through, then there might be sunk in the bottom of the cylinder a diving-bell, and the work might be done in that; and if an air-lock were provided at the top of the bell, the material could be got out.

In the discussion of this subject there was one name which should be mentioned with respect, but it was now seldom or never heard,—that was the late Earl of Dundonald, who, in the year 1830, when Sir Thomas Cochrane, devised and published,[3] in the most precise manner, information relating to the sinking of cylinders, which, so far as he could see, contemplated everything as yet done by the use of the compressed air. He thought when everything that was now known about cylinders and compressed air was treated, not in a speculative manner, but thoroughly in all its details, thirty years ago, by Sir Thomas Cochrane, it ought to be remembered, that it was to him that was really due a practicable mode of so sinking cylinders.

Mr. REDMAN remarked, that there was not the slightest difficulty

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. x., p. 353.
[2] *Ibid.*, vol. xxi, p. 268.
[3] *Vide* Specification of Sir Thomas Cochrane, A.D. 1830. No. 6018, "Apparatus for Excavating, Sinking, and Mining."

in balancing the pressure externally and internally, by admitting the water freely through the cylinder above the level at which the work was proceeding, thereby preventing any tendency to 'blow,' and thus not removing more material than was due to the cubical displacement of the cylinder. This course he had put in practice twenty-five years ago at Milton-on-Thames,[1] where cylinders were sunk by him through the sand and gravel of the alluvial Thames strata; and by allowing free admission of the tidal water above the working level, there was no difficulty in sinking the cylinders. The first pair of cylinders reached the chalk at the Royal Terrace Pier, Milton-on-Thames, on the 19th of August, 1843. With regard to the process of sinking cylinders by exhausting the air, Dr. Potts visited the works referred to while the cylinders were being sunk, at a date prior to his patent being registered, which was the 5th December, 1843.

The air lock for using compressed air was adopted successfully by French engineers, about thirty years ago, on the banks of the Loire; and it was described in the Supplement to Dr. Ure's 'Dictionary of Arts, Manufactures, and Mines.'[2] Wrought-iron cylinders were sunk 60 feet or 70 feet through semi-fluid strata of sand, over coal workings, thought previously to be inaccessible.

Mr. J. D. Baldry remarked, through the Secretary, in reference to the use of Mr. Milroy's Excavator at the bridge over the river Clyde, for the Glasgow (City) Union Railway, that the material passed through by the cylinders was fine sand, about 80 feet deep at the centre of the river, and the cylinders then took a firm bearing upon the carboniferous sandstone, or on the stiff boulder clay, which, in some cases, overlay the sandstone for a thickness of from 2 feet to 6 feet. The water was retained in the cylinder during the whole time of sinking. When the cylinders ceased to sink, borings were made at several places, near the side of the cylinder, to ascertain if the rock had been reached. When fully sunk, cement concrete was let down in boxes, the bottom of each box being in two pieces, hinged and fastened by a catch, and the contents were released on pulling a rope attached to the catch. This answered very well, and after a few days, a depth of 5 feet of concrete was found sufficient to keep out the water. This depth was, however, generally exceeded before the water was taken out, and the concrete in hydraulic lime was then put in dry, and carried up to 12 feet below low water. Above this level, brickwork in hydraulic lime was laid to the top of the cylinders at the junction with the octagonal column. The weights were removed as they were reached. The proportions used for the cement concrete were 1 of cement,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv., p. 222.
[2] *Vide* Dr. Ure's Dictionary, Supplement, 20th March, 1845, pp. 261, 262.

$\frac{1}{2}$ or $\frac{3}{4}$ of sand, and 4 of broken stone; for the rest of the concrete the proportions were $1\frac{1}{4}$ of sand, 1 of Arden lime, and 4 of broken stone. The average depth sunk was latterly 12 feet per day, which included putting together, fitting, &c.; but as a trial, on one occasion, a depth of 25 feet was sunk in ten hours, during which time 70 cubic yards of material were removed from the cylinder, at the rate of about $\frac{3}{4}$ of a cubic yard each lift. The machine had been of considerable value throughout, and at the great depths penetrated, both as a matter of economy and of rapidity of work, it far exceeded anything previously done by other methods. The cost of sinking was £1. 10*s.* 2*d.* per ton on the weight of the cylinders sunk. This allowed £1 per ton for the use of the weights (about 220 tons were used) and all labour, cost of jointing, materials, &c., with proportion of prime cost of engines, of which there were two of 12 H.P. each. The staging was included in the general structure of the bridge, but separating this, 'pro rata,' as near as might be, it would add about £1. 5*s.* 2*d.* per ton to the cost of the cylinders. No boulders, or other obstructions of a like nature, were met with, and at this part of the Clyde there was comparatively little navigation.

In the Hutchesontown Street bridge, now in course of erection over the Clyde by the Corporation of Glasgow, cylinders were also used for the piers, for sinking some of which Mr. Milroy's Excavator was adopted with a slight alteration; the blades being attached to a circular frame, 5 feet in diameter and 2 feet 3 inches deep, so that $1\frac{2}{3}$ cubic yard could be raised at each lift, or nearly double the previous work.

Mr. Milroy explained, through the Secretary, that an engine of 12 H.P. was not absolutely required for the Excavator used at the Clyde Bridge, as a larger one was then being worked by a weaker engine; but, in his opinion, excess of power was always to be preferred to the opposite. The rate, however, of the cost of sinking with the Excavator—if calculated by dividing the total outlay by the number of tons of cylinder sunk—would be found to be lower than by any other machine with which he was acquainted. Whatever might be the case with other machines, it was a mistake to suppose that the Excavator was liable to get out of order. Though specially invented for the purpose of executing the Bridge over the river Clyde for the Glasgow (City) Union Railway, after the preliminary experiments with the first cylinder, the Excavator never once got out of repair, either there or at any subsequent works. Consequently, the details in the Paper were subject to no deduction for loss of time; the time occupied in erecting the staging, &c., was omitted, as being the same as at any other bridge, and, therefore, as being irrelevant in a description of the Excavator. With regard to

the remark that, in quartz and limestone boulders, the Excavator would be sure to work at a great disadvantage, it was sufficient to say, in reply, that the ordinary Excavator used in sand had brought up large boulders whenever it had encountered them, and had sunk cylinders at Wapping, through the Thames gravel, and into the London clay. The object of his remarks on the removal of the water from the interior of the cylinder had been misunderstood. So far from advocating it as a 'mode of sinking,' all that he aimed at was to remove the pressure of the heavy column left in the cylinder at the ebb of the tide, and to establish a slight preponderance in favour of the water outside. He did not think there was any choice between the Excavator and the Sand Pump on the ground of simplicity. A more comprehensive comparison was necessary in order to arrive at an estimate of their relative merits; and, as the inventor of the Excavator, he might be permitted to point out wherein its superiority in his opinion consisted. Leaving the pneumatic process out of account, as not being properly an excavating apparatus, he thought the Excavator was superior to the Sand Pump, to the perpendicular dredger, and to hydraulic digging, in the important quality of Power. Their inferiority consisted in attacking the large area at the bottom of the cylinder only at a single point in the centre, in depending, therefore, on the earth falling in towards that point, in proceeding by slow processes, and in operating by weak agencies, such as pumping. Whereas the Excavator attacked the whole area of earth at once, grasped instantaneously its load of one or two cubic yards, and could be driven into the ground and filled, not only by its own weight, but by any amount of sheer force that might be required. This superiority in Power told in a marked degree in the Speed of excavating and sinking. Even the high rate given in the Paper understated the capabilities of the Excavator; for it had been found, since the completion of the Clyde Bridge, that with a deeper and more capacious machine, the rate of excavating and of sinking might have been nearly doubled. It told also in a superiority in Range, being applicable to a greater variety of circumstances; for whereas the other appliances, with the partial exception of the dredger, were limited to soft, sandy ground, the Excavator could work not only in soft, but in hard strata. It had brought up large boulders, had sunk through ordinary gravel, Thames gravel, mud, sand, and marly clay. It had excavated the London clay to a sufficient depth to admit of the water being pumped out, beyond which point it was not required to go. In short, it had not only gone further than the other machines towards overcoming easily and economically the difficulties of sinking, but it would seem that the sphere of its applicability was co-extensive with the sphere of those

difficulties. For instance, if a clay were encountered so stiff that the Excavator could not excavate it quickly, its use would become no longer necessary, because the water could then be pumped out. These three qualities of superior Power, Speed, and Range, united in conferring on it, without any sacrifice of simplicity, superiority in usefulness, and in economy. The acquisition of greater advantages was at the same time accompanied by a saving of expense.

March 9, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

Before commencing the ordinary business, the President referred to the recent decease of one of the oldest Members, Mr. James Simpson, Past President of The Institution of Civil Engineers. The President observed that Mr. Simpson had left a name which would long be remembered with honour;—by the world as a man of the most upright character, and a distinguished hydraulic Engineer;—by The Institution of Civil Engineers as one who, for many years, was a most regular and valued attendant at the meetings;—and by those who enjoyed his intimacy as a faithful and devoted friend.

No. 1,230.—"American Locomotives and Rolling Stock." By Zerah Colburn, M. Inst. C.E.

In construction and working the American railways represent little more than a modified application of English practice.

When the systems of the railway machinery of the two countries are compared, many of the differences which first strike the eye are found to be external rather than fundamental; and so, too, many of the peculiarities of construction now retained in America will be found to be due to the initiative of English engineers. But for the necessities of a new country, and the comparative scarcity of capital, American railways and their rolling stock would have doubtless been constructed, as in other countries, upon English models, and worked, in most respects, upon English principles of management. The first two locomotives worked in America were made in England, in 1828, one by Mr. George Stephenson, the other by Mr. J. U. Rastrick, then of Stourbridge, for a short line owned by the Delaware and Hudson Canal Company. They were both of the early Stockton and Darlington pattern, with single-flue boilers, and they were thus deficient in steam power for working the gradients of the line, while they were also much too heavy for its primitive permanent way. In 1828 also the engineers of the Baltimore and Ohio Railroad (not then begun) visited England; and the late Mr. Robert Stephenson once informed the Author, that he suggested to them, what is now the chief distinguishing feature of all American railway rolling stock, viz., the bogie, to be

applied to the engines intended to work round curves of 6 chains radius, at that time proposed to be adopted. The bogie, which had grown out of William Chapman's invention of 1812, was then, Mr. Stephenson stated, in regular use upon the quays of Newcastle. With few exceptions, the railways then contemplated and afterwards constructed in the States were surface lines, with frequent and often comparatively steep gradients, sharp curves, and a cheap and weak permanent way, if indeed the latter term can be properly applied at all. It was essential that the locomotives for such lines should be both light and cheap, and the first engines made in the States, between 1830 and 1832, weighed but from $3\frac{1}{2}$ tons to 4 tons. Some of the English built engines imported at about the same time had their leading wheels removed, and a swivelling bogie substituted. The bogie was not, however, exclusively employed. Considerable numbers of engines made by Messrs. Stephenson and Co., Messrs. Bury, Curtis, and Kennedy, Messrs. George Forrester and Co., and Messrs. Braithwaite and Co., were afterwards imported and worked as originally constructed; and in 1834 the Locks and Canals Company of Lowell, Massachusetts, commenced, and for several years continued upon an extensive scale, the construction of locomotives of the type fixed by Messrs. Stephenson and Co. for the Liverpool and Manchester engines. At least one hundred locomotives of English construction, or made almost exactly upon Messrs. Stephenson's plans, could have been counted at work in the States as late as 1855; and there may be some, here and there, at work still. For many years wood only was employed as fuel, and as it produced great quantities of sparks, as annoying to passengers as they were dangerous to goods, much ingenuity was directed to the problem of separating and withholding them from the escaping smoke and steam; and the voluminous and toppling erections, under the name of 'spark arresters,' of nearly every shape between that of a mill-hopper and a balloon, which bestride the smoke-boxes of American engines, are very successful in this respect, while they also give an unmistakable individuality to the engines themselves. Nor was it long before the rigours of the American winters compelled the adoption of some kind of shelter for the enginemen and firemen. The bulky, and often extravagantly painted and decorated 'cabs' which distinguish the American locomotives at once strike the eye, and impart a novel and foreign appearance to the whole design; yet it need hardly be said, that they in no way affect the principles, or economical conditions of working, of the engine itself.

As already observed, the bogie or swivelling truck is the chief distinguishing feature of American locomotives and railway rolling stock. It permits of almost any length of wheel-base upon sharply curved lines, and it thus secures an amount of steadiness in the

engines and rolling stock to which it is applied quite unattainable with the disposition of wheels more ordinarily adopted in England. As made in the States, the bogies are not only singularly cheap in first cost, but are durable and inexpensive in maintenance, and it will be shown in the course of the present Paper that they work with a very low tractive resistance.

Keeping in mind the distinguishing merits of the bogie, the other differences between English and American locomotives are differences more of costume and of toilette than of vital principles of construction. The earlier engines had each a single pair of driving-wheels, but these bore a good proportion of weight for adhesion, partly because the centre of the bogie was 2 feet or 3 feet forward of the position occupied by the leading wheels in Stephenson's engines, and partly because a portion of the weight of the tender was made to bear upon the foot-plate. The last-named mode of increasing the adhesion was followed for years, more as a neat trick, however, than as an acknowledged expedient, yet it was duly patented in 1835; and it is a question even now, whether it would not be better to adopt it, rather than to load the foot-plates of so many goods engines with heavy cast-iron dead weights to increase the adhesion.

As high speeds were but seldom attempted upon the early American lines, the greatest steam tractive power was sought and obtained, both by working high-pressure steam and by employing driving-wheels of small diameter. Thus, although, in 1835, the English-built engines, and those copied from them, were worked at 50 lbs. pressure, and had only 5 feet driving-wheels, it was not long before American practice settled upon 90 lbs. to 100 lbs. pressure and 4 feet or even 3 feet 8 inch driving-wheels. It was soon found, however, that the adhesion weight upon a single pair of wheels, necessary to work up this increased steam tractive force, was too great for the strength of the way, and coupling was then resorted to; and in 1839 the eight-wheeled engine, with four coupled wheels and a bogie, came into extensive use. Mr. Joseph Harrison supplied a simple yet most valuable improvement, that of the compensating levers, whereby the weight was not only equalized between the coupled wheels, but the effect of a jolt upon one pair of wheels was divided and distributed, through the springs and levers, upon the other pair. It is for the latter reason, and hardly for any other, that compensating levers are now employed on all American engines, and those who have once witnessed their action upon rough lines cannot understand why they are not more used in English practice. It has now been usual for some years to make the outer ends of the springs of the coupled wheels bear upon india-rubber blocks; and even the compensating levers have been made of long steel springs; but without the last-named

refinement, the subdivision of the shocks, occasioned by low joints or depressions in the rail, is most complete and effective.

The comparatively weak and imperfect permanent way of American railways required a greater subdivision of the rolling weights than in England, and, with the exception of a few light tank engines, worked on branch lines, there is not probably an engine in the States having single or uncoupled driving-wheels. It may be said that a weight of 4 tons has been the maximum per wheel for many years, while 3 tons was the more usual average. Ten-wheel engines, having six coupled wheels and a bogie, weighed less than 3 tons upon each of their coupled wheels, and the eight-wheel coupled engines, long worked on the Baltimore and Ohio and Reading Railroads had but 3 tons on a wheel, although they had cylinders of the large diameter of 19 inches, with 22-inch stroke, and 3-feet-7-inch coupled driving-wheels. The tons quoted are English tons, the ton more generally understood in the States being the New York ton of 2,000 lbs.

While the subdivision of weight referred to involved the coupling of a greater number of wheels, their size was so moderate, indeed in many cases so very small, that they could almost always be grouped together over a wheel base of moderate length. The base of the eight-wheel coupled engines, to which allusion has just been made, was only 11 feet 3 inches, the 3-feet-7-inch wheels being placed but 3 feet 9 inches apart from centre to centre, while only the leading and the trailing wheels had flanges. The subdivision of weight has been carried to the extent of ten, twelve, and fourteen-wheel engines, and of these some have six, some eight, others ten, and one twelve wheels coupled and worked by a single pair of cylinders. These are in all cases goods or bank engines intended to work at slow speeds, although a twelve-wheel engine made in 1855 by Mr. Ross Winans was intended for working passenger trains over the long inclines of 1 in 45½ of the Baltimore and Ohio Railroad. This engine had 22-inch cylinders, 22-inch stroke, eight coupled wheels, 3 feet 7 inches in diameter, and a bogie. The weight per wheel averaged but 3 tons, and the extreme wheel base was under 17 feet. On the Reading Railroad are a moderate number of engines with ten coupled wheels and a bogie, the average weight being under 3 tons per wheel. There is also a ten-wheel coupled engine weighing 50 tons, and having 5 tons on a wheel, employed to work the incline of 1 in 16½, and 1¼ mile long, at the Madison Terminus of the Madison and Indianapolis Railroad. This engine has twelve coupled wheels 3 feet 11 inches in diameter, and loaded to 3¾ tons to a wheel, the total weight being 44¾ tons. It has 20-inch cylinders, and 26-inch stroke, and is employed to assist coal trains, of a gross weight of 850 tons, up a bank of 1 in 155, and 1½ mile long. The line being mode-

rately straight, no difficulty is experienced from the considerable length of wheel base, which is 19 feet 7 inches. Compared with English practice, in which six-wheeled coupled engines have from 5 tons to 6 tons on a wheel, and the eight-wheeled coupled engines, weighing 56 tons, (of which two are employed at the London end of the Great Northern line,) have 7 tons on a wheel, it will be seen that the subdivision of weight in American engines is carried about half as far again, or, in other words, that they average only about two-thirds as much weight per wheel, and that they thus require, for a given total weight, half as many more wheels. Except with smaller wheels, this could not be done upon any practicable length of wheel base; but none of the American goods and bank engines, of which the particulars have been given, have wheels larger than 3 feet 11 inches in diameter. There are objections also, of much weight, to coupling a large number of wheels from a single pair of cylinders. It is more or less difficult, if not impossible, to preserve an exact equality in the diameters of the wheels, an exact parallelism of the axles, and an exact equality in length of the coupling rods. The extent to which coupling has been carried in American goods engines has been due, in a great measure, to the following expedients:—The coupled wheels were as equally loaded as possible; their tires, in a majority of cases, were of chilled cast iron, since replaced by steel; and the former were cast, and the latter turned, nearly or quite to a cylindrical form, or with but little or no cone. The driving-wheels were the middle pair, or, in the case of an even number of pairs, one of the pairs nearest to the mid length of the wheel-base; compensating levers were employed, and adjusting wedges have for some years been applied to the axle-boxes. The coupling rods, in many cases, were made without brasses, round steel bushings being fitted to circular eyes formed at the exact required distance apart in the ends of the rods. With the exception of the leading and trailing wheels, the coupled wheels were more generally fitted with plain cylindrical tires having no flanges. Outside coupling cranks, necessary with outside frames, have rarely been employed, and are now wholly abandoned. The coupling rods are counter-weighted within the wheels themselves, no attempt being made, in inside cylinder engines, to set off their weight against that of the cranks and attached parts. In other words, the coupling pins of the driving-wheels are coincident, on each side of the engine, with the position of the crank in inside cylinder engines, and, of course, necessarily so in outside cylinder engines. The experience of American locomotive engineers has been to the effect that with this arrangement, which is the opposite of English practice, the axle boxes wear more uniformly, and that there is less 'knocking,' where a little play in

the horn plates has once begun. And lastly, the length of the crank being one-half the radius of the small coupled wheels employed, any inequality in the length of the coupling rods is attended with less slipping and binding than where, with larger wheels, the crank is but about one-third the radius of the wheel. These various expedients and facts, taken in connection with the very moderate weight upon each wheel, and the moderate speed maintained, have enabled coupling to be more extensively, if not more successfully, carried out in the States than in England. It appears to be well settled also that coupled engines work more 'sweetly' when fitted with a bogie than when not so fitted, and the bogie, especially Bissell's, permits of a much longer wheel base than is safe when the leading axle is set permanently square across the engine.

Although a great variety, and often extraordinary types, of engines have existed in the States, but one general form of passenger engine is now retained. It has in most cases outside cylinders,—indeed inside cylinder engines have not been built for many years,—and it invariably has four coupled driving-wheels, and a four-wheeled bogie. As a general representation of all the passenger engines now built, it may suffice to describe one constructed at the workshops of the Chicago and North Western Railroad; and although having driving-wheels but 5 feet 8 inches in diameter, it has run a special train, probably of no great weight, 91 miles in 95 minutes, of which run 51 miles were made in 49 minutes, as certified by Mr. Cushing, Locomotive Superintendent of the line. High speeds are not, however, maintained on American lines, and no express train is timed to more than 32 miles in an hour, nor to more than 27 miles an hour in a run of 300 miles, although in this case the stops are longer and more frequent than on English lines. The speeds of passenger, and even so-called express trains, are more generally from 20 to 25 miles an hour, while average speeds of from 14 to 18 miles an hour are scheduled in the time-tables of many local lines in the Western and Southern States. Nor does the American Bradshaw (Appleton's Guide) show a single instance of a continuous run without stopping of more than 40 miles, and those of even 32 to 36 miles are unfrequent, most of the so-called expresses stopping at more frequent intervals, often at distances of from 10 to 15 miles. For such service an adhesive weight of from 14 to 16 tons, moderate-sized driving-wheels and cylinders, and the means of working full steam pressure for nearly the whole stroke in starting, are all that is required. The leading dimensions of the representative type of passenger engines are:—cylinders from 15 inches to 17 inches in diameter, with a length of stroke of from 22 inches to 24 inches, and coupled driving-wheels of from 5 feet to 5 feet 8 inches

in diameter. Such engines will exert a tractive force of $3\frac{1}{2}$ tons to 4 tons in starting, for which their adhesive weight, assisted sometimes by sand, is sufficient; and thus they can get quickly away from stations even with trains of a gross weight of 200 tons or more. Economy of fuel has not been studied to the same extent in American as in English locomotives: the blast pipes of the former are smaller, the draught more forced, the back pressure greater, and less expansion is attempted in the cylinders, the link motion being generally arranged to cut off at one-third stroke as a minimum, and nine-tenths or more as a maximum. It is thus that boilers of moderate size are made to supply steam for work equal to 300 indicated H.P., or the exertion of upwards of 2 tons of draught upon a passenger train at a mean speed of 25 miles an hour; but there is nothing remarkable in the consumption of from 50 lbs. to 60 lbs. of coal per mile in such work.

As relating to the consumption of fuel the Pennsylvania Central Railroad may be instanced. Its main line is 356 miles long, the eastern and western portions having gradients of 1 in 100, while its middle division has but very moderate ascents; for a few miles, however, on the western division, there are gradients of 1 in 55, up which the goods trains are assisted by pushing engines. Of four hundred and nine engines on the line in October, 1868, two hundred and forty had six coupled, and three had eight coupled wheels of from 3 feet 8 inches, to 4 feet 6 inches in diameter, the larger number having 18-inch cylinders with 22-inch stroke. The standard pattern of passenger engines had 17-inch cylinders, 24-inch stroke, and four coupled wheels 5 feet to 5 feet 6 inches in diameter, and of this class there were upwards of one hundred. The mean speed of fast passenger trains is about 25 miles an hour, and of other passenger trains about 23 miles an hour, yet the consumption of coal for both goods and passenger engines averaged respectively, on the eastern, middle and western divisions 52·7 lbs., $66\frac{3}{4}$ lbs., and $70\frac{3}{8}$ lbs. per engine mile, corresponding to a general average of about 70 lbs. per train mile, the goods mileage being about three and a half times the passenger mileage. The coal is of excellent steaming quality, and is found so near at hand, and in such abundance, that its cost is after all but about $3\frac{1}{2}d.$ in currency, or $2\frac{1}{2}d.$ in coin, per train mile. At this rate a difference in consumption of 24 lbs. of coal per mile would only cause a variation of a penny per mile in the cost of fuel, and it has been argued that such a waste is better than the alternative of employing an engine 4 tons or 5 tons heavier, to work with a less rapid rate of combustion, a slower piston speed, and more expansively. It is to be remembered that for every pound of coal burnt, from 6 lbs. to 7 lbs. or 8 lbs. of water require to be provided, and an additional weight of at least half as much in the

structure of the tender itself is necessary to carry it. Thus if an engine burn 67 lbs. of coal, and consume seven times the weight, or 469 lbs. of water per mile, and stops every 33½ miles, it will require to start with at least a ton of coal and 7 tons of water, the average weight of both, progressively consumed over the whole distance, being 4 tons. If the coal could be economized one-fourth, the average weight of coal and water would still be 3 tons; and it appears better, therefore, where fuel is so cheap, to waste a portion of it, perhaps a considerable portion, than to economize it by adding 4 tons or 5 tons of weight to the engine, to obtain a larger boiler, and working gear admitting of a slower piston speed and a higher grade of expansion. The question turns upon the cost per ton per mile of moving a passenger engine and tender, but much more upon the length of run without stopping; upon whether the water may be picked up along the line or taken only at stations; and upon the original cost and the interest on it, the repairs, and the depreciation of the engine. Every locomotive engineer can easily examine the question in the light of these circumstances, as applying to his own line; and it might be found in some cases that it would be absolutely cheaper to employ engines burning 40 lbs. of coal per mile than heavier and costlier engines burning but 30 lbs.

Much of what has just been observed of the passenger engines applies with even greater force to the goods engines. Of but moderate total weight, they have large cylinders and small wheels, and they draw heavy trains at a fair speed with a consumption of coal often amounting to 100 lbs. or more per mile. One instance, taken from the regular working of the standard type of goods engine on the Pennsylvania Central railroad, will suffice. This class of engines has ten wheels, of which six, each 4 feet 6 inches in diameter, are coupled. The whole weight of the engine is only 31⅛ tons, and of this but 23½ tons rest on the coupled wheels, available for adhesion. The cylinders are 18 inches in diameter, with a length of stroke of 22 inches. With 60 lbs. mean effective pressure per square inch upon the pistons, these engines would exert a tractive force, less their own internal resistances, of rather more than 3½ tons, or about one-seventh of their adhesion weight, although in starting a train, or in ascending a gradient, with 100 lbs. pressure on the pistons, the steam tractive force would be 6 tons, equal to more than one-fourth of the adhesion weight, the efficiency of which would then be assisted when necessary by sand. There are thirty of this class of engines, besides many others of nearly the same weight and dimensions, on the middle division alone of the Pennsylvania Central line; this division being 132 miles long, and gently descending for nearly its whole length to the eastward, the only exceptions worth

noticing being 300 yards up 1 in 293, and 400 yards up 1 in 352. The regulation load going eastward, in which direction only the wagons are nearly or fully loaded, is forty-five eight-wheel wagons, each weighing $7\frac{1}{2}$ tons empty, and $16\frac{1}{2}$ tons loaded, making a total load of 743 tons. The total fall in the 132 miles is 851 feet, equivalent to an average descent of 1 in 808 for the whole distance. Yet in October last, 1868, the average consumption of the best bituminous coal by these engines was 100 lbs. per mile, in addition to the wood employed for lighting, and the average for all engines, passenger and goods, one hundred and fourteen in number, was $66\frac{3}{4}$ lbs. per mile. On the same division, two engines, having six wheels coupled and a two-wheel bogie, the whole weight being $31\frac{3}{4}$ tons, of which all but $2\frac{1}{4}$ tons were available for adhesion, were loaded to heavier work. They had 19-inch cylinders, 24-inch stroke, and 4 feet coupled wheels, and with 60 lbs. mean effective cylinder pressure would exert a tractive force, less their own internal resistances, of 4·83 tons, equal to about $\frac{1}{6}$th of the adhesion weight. The distance run by these engines averaged 100 miles a day each, with a consumption of coal respectively of $127\frac{1}{2}$ lbs. and 104 lbs. per mile. Their regulation load going eastward was sixty eight-wheeled wagons, weighing, when fully loaded, 990 tons. It is not probable, however, that they were always fully loaded, nor even if they were, can an accurate estimate of the resistances be formed. Yet if the latter be taken, after allowing for gravity in favour of the eastward trip, at $8\frac{5}{8}$ lbs. only per ton, for a train, engine and tender included, of 1,040 tons weight, the total resistance would be 4 tons, and thus the work done on each mile would be equal to 24 H.P. exerted for one hour. For

$$\frac{5{,}280 \text{ feet per mile} \times 8{,}960 \text{ lbs. (4 tons)}}{1{,}980{,}000 \text{ foot lbs. per H.P.}} = 24 \text{ H.P. per hour}$$

nearly; so that, could these estimates be trusted, the consumption of coal per H.P. per hour would not after all exceed $4\frac{1}{4}$ to $5\frac{1}{4}$ lbs. The speed would not probably exceed 15 miles an hour, corresponding to 360 H.P. Exact data are unfortunately wanting to determine the dynamical effect of these engines, and it is not pretended that the general assumptions just made have any claim to exactness, although the Author is convinced, from a somewhat lengthy acquaintance with engines of the same general type, that the estimates above given are not very far wide of the mark.

The policy of American railway managers with respect to goods traffic, as it is also the policy of the managers of most of the French lines, is maximum loads at slow speeds, involving a minimum resistance per ton, and correspondingly a minimum working expenditure per ton. No experiments upon the dynamical efficiency of American engines have been made, so far as the

Author is aware, beyond general observations as to the load drawn and the consumption of fuel, the essential element of speed being too often omitted, while the evidence afforded by the indicator has almost invariably been wholly wanting. Yet experiments of some magnitude, which the Author conducted, appear by their results to show, that the resistance of bogie rolling stock, even under disadvantages, is less than that of English rolling stock as ascertained by the best authorities, and also that the ratio of adhesion to weight averages considerably more in the States than in England. With respect to adhesion, as the surfaces in contact are identical with those on English railways—indeed, the rails and tires in general use in the States are commonly of English manufacture—any difference in this respect must be attributed partly to the influences of climate and partly to a better application of sand, when necessary to increase the bite upon the rails. In the States, the rails are seldom in the condition known as 'greasy;' they are usually either quite dry or quite wet. Clean, sharp, dry sand is provided for use when wanted, and it is dropped equally upon both rails of the line, not by being poured in intermittent handfuls down a pipe on but one side of the engine, but by means of the hand gear and regulating valve adopted for the engines on the North London Railway.

In the autumn of 1855, the Author, at the request of Mr., now General, M'Callum, the Manager of the Erie railroad, took charge of an experimental train which he ran over the whole length of the line and back, a total distance of nearly 900 miles. The same engine was employed throughout the run, occupying in all nearly three weeks, making an average for each week-day of about 50 miles. The line is divided into four divisions, varying considerably in respect of gradients, and the utmost load the engine could draw was taken in both directions over each division. The maximum inclinations were 1 in 88. The results of the experiments were so voluminous, that it will be sufficient to detail the particulars of what may be termed crucial tests of adhesion and resistance to traction.

The engine had four coupled wheels and a bogie, the total weight in working trim being 29½ tons, of which 17⅞ tons rested on the coupled wheels available for adhesion. The coupled wheels were 5 feet in diameter; the outside cylinders were 17 inches in diameter, and the stroke 24 inches. The safety valves were set to blow off at 130 lbs., and the steam, as observed by a Bourdon gauge, was seldom allowed to exceed that limit. No indicator diagrams were taken, nor was any measure taken of the wood burnt, all that could be consumed by the engine, in maintaining the requisite steam, being supplied. The tender, loaded, weighed 18½ tons. The train drawn consisted of eight-wheel wagons fully loaded with

deals. The average weight of each wagon empty was 5 tons 8 cwt. 3 qrs., and of each wagon with its load 15 tons 5 cwt. 3 qrs. nearly. The wagons had cast-iron chilled wheels, each 2 feet 6 inches in diameter, with inside journals $3\frac{7}{8}$ inches in diameter, and 8 inches long. All the wagons had been put in complete order, and the journals, fitted with oil-tight boxes, were kept well oiled. The gauge of the line was 6 feet. The weather was most favourable, clear and dry, with the exception of a single day of heavy rain.

Upon about 100 miles of the line, forming a portion of the Susquehanna division, a train of one hundred wagons, weighing with engine and tender 1572 tons was taken. The train was a few feet more than half a mile in length.

At one point it was stopped where the line commenced an ascent of 24 feet in 4 miles, averaging 1 in 880 up for the whole distance. There were also long and easy curves upon this portion. The train was taken up and purposely stopped on the second mile, to be sure of starting again with no aid from momentum. The average speed up was 5 miles an hour, and neither was the pressure of steam increased nor sand used except in starting from the stops purposely made. The engine, even were its full boiler pressure of 130 lbs. maintained as effective pressure upon the pistons throughout the whole length of their stroke, could not have exerted a tractive force greater than $\frac{17^2 \times 130 \text{ lbs.} \times 2 \text{ ft.}}{5 \text{ ft.}} = 15{,}028 \text{ lbs.}$;

nor is it at all probable that the effective cylinder pressure could have approached this limit by from 10 lbs. to 15 lbs. per square inch. Supposing however, for the sake of a *reductio ad absurdum*, that the full boiler pressure had been maintained upon the pistons for the whole length of their strokes, the adhesion of the coupled driving-wheels, not deducting the internal resistances of the engine, would have been $\frac{15028}{40050} = \frac{3}{8}$ of the weight upon them. In any case there was a resistance of 4011 lbs. due to gravity, and if even 120 lbs. mean effective cylinder pressure be assumed, corresponding to a total tractive force of 13,872 lbs., the quotient representing the rolling and other resistances, exclusive of gravity, would be but 6·27 lbs. per ton of the entire train; a resistance including all the internal resistances of the engine, the resistance of the curves, easy although they were, and the loss in accelerating and retarding the train in starting and stopping. This estimate of resistance would correspond, at the observed speed of 5 miles an hour (upwards of three-quarters of an hour having been consumed on the 4 miles), to 185 indicated H.P., which with the driving-wheels making but twenty eight revolutions per minute, would be the utmost that an engine with but 1,038 square feet of heating surface could be expected to exert. This was the

highest result observed during the three weeks' trial, but one or two others are worthy of mention. On the Delaware division of the same line, the train, of 1,572 tons' weight, was run over 5 consecutive miles of absolutely level line, at a mean rate of 9·23 miles an hour, and, during the same day, over 5 other consecutive miles of level at a mean rate of 9·7 miles per hour. On both levels there were 14½ chain curves of good length, and the speed, from 9 to 12 miles an hour, at which the train entered the respective levels, was not quite regularly maintained throughout the half-hour expended in running over them. But if even 7 lbs. per ton of the total weight be taken as the resistance at these speeds, the tractive force will be 11,004 lbs., which is more than one-fourth the adhesion weight of 40,050 lbs. On the next day, the same engine drew thirty wagons weighing 466½ tons, or, including engine and tender, 514 tons nearly, up a gradient of 1 in 117½, three miles long, at a mean speed of 10¼ miles an hour. The resistance due to gravity was 9,814 lbs., and supposing the other resistances to traction to amount to no more than 7 lbs. per ton, the total resistance would be 13,412 lbs., corresponding to a mean effective cylinder pressure of 117 lbs. per square inch, and to a coefficient of adhesion of almost exactly one-third.

It is needless to repeat instances of much the same kind, as occurring during the experiment referred to. The Author is bound to say that they were, no doubt, influenced by the favourable circumstances of weather, and something is to be allowed also for the great length of train drawn, very long trains having a less tractive resistance per ton on a level than short ones, and something, possibly more than is commonly supposed, may have been due to the use of oil-tight axle-boxes, the saponaceous compound known as 'Railway Grease' being nowhere in use on railways in the States. It could not possibly be used, except in a congealed form, in the severe American winters; and Messrs. Guebhard and Dieudonné's experiments,[1] made in 1867, on the Eastern Railway of France, showed a very considerable diminution in the resistance of oil-boxed rolling stock as compared with that fitted with grease-boxes. But, weighed upon the other hand, are the facts, first, that the line was of 6 feet gauge, and, *pro tanto*, so much the worse for traction; secondly, that the wheels were comparatively small, and the inside journals of comparatively large diameter, the ratio of the former to the latter being as 7¾ to 1, instead of 12 to 1 as on English lines. It is difficult to believe that the length and steadiness of the double bogie goods wagons, scarcely liable as they are to lateral vibrations, had not something

[1] *Vide* "De la résistance des trains et de la puissance des machines," 8vo. Paris, 1868, p. 36.

to do with the result, which is in some respects unique in the history of railway traction. The result, although not absolutely showing the real resistance to traction, nor the real adhesion of the engine, presents this alternative, viz., that the resistance must have been unusually small, or the adhesion unusually large.

Of the mechanical details of American locomotives, considered apart from those already touched upon, much might be said. There are differences, and they are numerous, but they involve no important principles. The chilled cast-iron wheel, however, for engine and tender bogies, and especially for carriages and wagons, deserves special mention. No wrought-iron wheels, so far as the Author can learn, are now employed in the States, unless in a few cases for engine-driving wheels; and wrought-iron wheels, at first exclusively adopted, have been wholly abandoned by the engineers and managers of the Grand Trunk and the Great Western Railways of Canada. The cast-iron wheels are not only much cheaper, but they are more durable, and, if not safer, are at least equally safe. The wheels employed for passenger carriages are 2 feet 9 inches in diameter, and weigh 5 cwt. The bogie wheels of engines, tenders, and goods wagons are generally 2 feet 6 inches in diameter, and vary in weight from 4 cwt. to 4½ cwt. They are cast of special mixtures of the best qualities of iron, the requisite conditions being great absolute strength to resist both sudden and progressive strains, and the property of taking a deep and uniform chill. But little of the cast iron employed for wheels has a tensile strength of less than 15 tons per square inch, and it breaks with a fracture, almost suggestive of fibre, and of a dark-grey colour, but when chilled, of a silvery whiteness; the chill, at a depth of ½ inch, blending by almost imperceptible changes through another ½ inch, with the unchanged and softer iron beyond it. To break off the flange of the wheel at any point by the heaviest blows of a 28 lb. sledge, wielded by a strong man, is a long and laborious task, and to break up the wheel altogether is, *à fortiori*, still more difficult. The chilled wheels run from two to six and even seven years, according to the traffic, before becoming so much worn as to require removal. During all this service of from 80,000 miles to 200,000 miles, they do not require, or rather they do not admit of, turning down, and when at last condemned, they are worth generally about half their original cost as old iron. The present cost reduced from currency into gold, and into English money, is, for the 5 cwt. wheels, for passenger carriages, from £3. 6*s*. to £3. 10*s*. each, or from £13. 4*s*. to £14 per ton; while wheels 2 feet 6 inches in diameter, and weighing 4 cwt., are sold at the rate of about £11. 8*s*. per ton. These prices represent an originally high price of iron, dear labour, and excessive government taxation. In the last-named respect, the ingenuity, not to say genius, of the framers of the protective system,

surpasses anything that can be said of a corresponding nature of the American railway system. Besides taxing the incomes of the owners of the minerals requisite for making the iron, and those of the manufacturers through whose hands it subsequently passes, there is a special tax upon the iron, as such, a further tax upon it as a wheel, and a still further tax upon it as a component part of a railway carriage.

It should be mentioned, that engine driving wheels of from 4 feet to 5 feet in diameter, have been cast with chilled faces, thus requiring no tires, and chilled tires, from 4 feet to 6 feet in diameter, and $3\frac{1}{2}$ inches thick, have been extensively and successfully employed at fair rates of speed, say 28 miles an hour. At one time the Baltimore and Ohio Railroad Company had not a single wrought-iron or steel tire on their whole stock of engines, then numbering about two hundred and twenty-five.

Wood was almost exclusively employed as fuel, except upon two or three important lines in the coal districts, until within the last ten or twelve years. Iron fire-boxes and copper tubes were generally adopted; and for both the fire-boxes and the barrels of boilers, from $3\frac{1}{2}$ feet to 4 feet in diameter, and worked at from 100 lbs. to 130 lbs. pressure, iron of but $\frac{5}{16}$ inch thickness was generally used, and in many cases the thickness was but $\frac{1}{4}$ inch. At the present time coal is burnt wherever it can be obtained at a less cost than wood. A 'cord' of wood (the 'cord' being an old English measure now obsolete here) is a pile of billets cut in 4 feet lengths, and piled 8 feet long and 4 feet high, thus forming a bulk of 128 cubic feet. Its cost, according to locality and quality, ranges from 10*s.* to 30*s.*, yet its heating value is equal to that of but from 10 cwt. to 15 cwt. of coal, varying according to quality. The cost of wood fuel, on the railway system of the State of New York, averaged $7\frac{1}{2}d.$ per train mile as long ago as 1855, and on some of the leading lines it was as high as $15d.$ In the case of goods engines burning 100 lbs. of coal per mile, a rate of which examples have been given, a cord of wood would last but from 11 miles to 16 miles, and at the higher price just given, would cost from 1*s.* 11*d.* to 2*s.* 9*d.* per mile, the last-named sum being greater than the total working expenses of English lines.

For burning coal, steel fire-boxes and iron tubes are now adopted. Of upwards of four hundred steel fire-boxes in the engines of the Pennsylvania Central Railroad, some have been in use six years or more. The tubes are set without ferrules, and very little trouble, as the Author is informed by the General Manager of the line, is experienced either from leaking or cracking.

The boiler-work of American engines falls short of the standard in respect of strength and finish, maintained by English locomotive engineers; and boiler explosions, although not conspicuously

numerous, are certainly much more numerous in the States, even after allowing for the fact that fifteen thousand locomotives are working on their railway system of 42,000 miles, as against ten thousand locomotives on 15,000 miles of line in the United Kingdom. But it is worthy of observation that the evil of 'furrowing,' by no means uncommon in this country, is unknown in the States, and no other explanation appears available, than that the thinner iron employed there permits of a certain elasticity in the structure of the boiler, sufficient to prevent the localisation or accumulation of bending or other strains at particular points, or rather upon particular *lines* of resistance.

Apart from all æsthetic considerations, and regarded only from its commercial aspect, the preternaturally gaudy exterior of the American engines involves neither great original cost nor much cost for maintenance. Indeed it is believed in the States that a showily-decorated and coloured engine—and the Author grieves to state that even the diagrams do but scant justice to the lavish expenditure of sheet brass and polychromatic pigments which ornament, or otherwise, the locomotives at work there—is, after all, the cheapest in maintenance. The locomotive engine shown in the American department of the Paris Exhibition was overdone, even to an American eye, but its German-silver boiler casing and chimney casing were not so very far in excess of what almost any locomotive maker in the States is ready to turn out, or any of his customers prepared to pay for. The planished Russian iron, ordinarily employed for covering boilers, is not dear; it is very durable, and it only requires the daily application of a handful of greasy cotton waste to preserve its deep-sea, or lustrous indigo brilliancy. The painted work must stand upon the merits of its own varnish. The ornamental brass-work is quickly got over, and a pennyworth of rotten stone goes a long way with it. The engine-driver or engine-man, known to American minds as the 'Engineer,' fettles and grooms his engine for the love he bears to it; and his fireman, who looks forward to early promotion, is always ready to do his full share of work of this kind, *con amore*. It cannot be imagined that the gaudy decoration of locomotives, with such objects in view, would lead to the slightest advantage if attempted on English lines. In other respects, American locomotives present, in their external finish, more bright work polished upon a grinding stone than English engines. In their structure, too, there is a much more extensive use of cast iron, as in the driving and bogie wheels, the cross heads, the eccentric hoops, &c. But it is to be mentioned here, as the result of an intimate acquaintance with both the design and working of rolling stock in the States, that, for the especial purposes named, cast iron is preferred as much for its strength, and, when

not subjected to great friction, for its good wearing qualities, if not even more than for its original cheapness.

What are now understood as steep, or exceptionally steep, gradients, are rare in the States. The engineers of that country were perhaps the first to adopt long inclines of from 1 in 45 to 1 in 90, but from considerations of cheapness of construction only. Indeed, so long ago as 1838, a short line, the Hudson and Berkshire, was opened with an incline 1,232 yards long, and rising at the rate of 1 in 28·7 or 184 feet per mile, and this has been regularly worked ever since by engines of ordinary construction. This and the incline of 1 in 16½ at Madison, Indiana, are the steepest, it is believed, now worked by locomotive power in the States. The last-named incline, 1¼ mile long, was worked for nearly twenty years by four-cylinder engines gearing into a rack rail, as in the early plan of Blenkinsop. A tank engine weighing 50 tons, and having ten coupled wheels, each 3 feet 8 inches in diameter, supporting the whole weight, is now employed. It has 20-inch cylinders and 24-inch stroke, and with 145 lbs. boiler pressure has drawn up twice its own weight behind it at a speed of 5 miles an hour. On an incline of this pitch, $\frac{2}{3}$rds of the weight of the engine are lost for adhesion, a weight of 50 tons pressing upon the rails with a force of but 47 tons. The ordinary load is a little less than the weight of the engine. The working of temporary inclines of 1 in 10 on the Baltimore and Ohio Railway, and of 1 in 18 on Mr. Ellet's Mountain-top Track, has been fully described to the Institution in Mr. Isaacs' Paper, read in 1859.[1] Mr. George Escol Sellers, of Cincinnati, constructed five engines, prior to 1853, for the Panama Railway, on which it was proposed to lay down the mid rail. These engines had four cylinders each, two of them driving a single pair of horizontal gripping wheels by means of bevil gearing. The Panama Railway has no gradients, however, exceeding 1 in 88, and such engines were wholly unnecessary and consequently they were never put to work. This was the case, also, with two much heavier engines made by the same maker in 1856, for a mineral line in Pennsylvania, having inclines of 1 in 27. Mr. Sellers' engine is more or less known to English engineers by his patent of 1847, granted in the name of his patent agent, Mr. Newton.

It may be mentioned, that in July, 1836, one of Norris's engines weighing 6 tons 8½ cwt., and drawing behind it, including tender, a load of 8 tons 11½ cwt., ascended an incline near Philadelphia of 1 in 14, and 933 yards long, at an average speed of 15¾ miles an hour. The nominal weight on the driving-wheels was 3½ tons, but it is believed that a portion of the weight of the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii. p. 55.

tender was made to bear upon the foot plate, thus increasing the adhesion.

In attempting any comparison of the cost of maintaining locomotives in this country and in the States, a great variety of considerations must be weighed. The reported cost in America is given in a paper currency of fluctuating value, and must be first reduced to a specie standard. Even then the cost of labour and of iron, copper, &c., indeed of nearly all materials (excepting wood), which enter into repairs, is much greater than in Great Britain. The average cost of engine repairs in the States, exclusive of those renewals which amount to building a new engine, may be taken as a maximum at 10 cents currency, per train mile, equal to $3\frac{3}{4}d.$ in coin. Of this, the absolute difference in the cost of labour and materials would account for nearly or quite $1d.$, leaving $2\frac{3}{4}d.$ to $3d.$ as the cost at English prices. But the elements of comparison are still unequal. It is impossible to say what in each country are the relative proportions of the whole cost of repairs as due to accidents and as due to ordinary wear and tear. It is certain also that the rigours of the American winters tell more heavily in repairs than in this comparatively mild climate. Again, engine repairs are conducted, upon American railways, in a manner which, regarded from an English view of railway economy, shows great want of system and organisation. While every short line of 100 miles or so has its repair shop for its twenty or thirty engines, the great lines, with from two hundred to five hundred engines, have three, four, or more principal shops, wholly independent of each other, each having its separate managing and clerical staff, responsible only to the locomotive or general superintendent. The engines are not designed by the company's engineers, but are of widely different patterns by competing makers, who conform only to certain general dimensions. Nor are the repair shops—at least they were not when the Author was last in the States—fitted with some of the appliances considered essential to English engine shops. Overhead travellers were hardly thought of, nor were double headstock lathes for turning both tires of a pair of wheels at once. Hardly any machinery whatever is used in boiler making, and the smithy plant would not compare with that in English shops. Stamped forgings appear to be almost or quite unknown. Vice work is largely employed where machine work would be substituted in this country. The system of piece-work is not carried out to so great an extent; nor is the management so efficient, the men being left to a great extent to work upon their own responsibility, and but seldom with the aid of exact drawings, or, indeed, drawings of any kind. The variety of patterns, the want of templates, and the high interest upon capital, often prevent

a proper assortment of duplicates being kept in stock, and thus, and in other ways, repairs are conducted at a disadvantage. Again, a larger proportion than is the case here of the whole traffic is goods traffic, carried on in long and heavy trains, and, as has been shown, at an expenditure of from 75 lbs. to 125 lbs. of coal per train mile, an expenditure no doubt more or less wasteful, yet indicative of hard work. Even when the extreme subdivision of weight of American engines is considered, and the consequently lessened wear on the tires is allowed for, it is to be borne in mind that there are so many more tires to wear and to be turned down; and that a 31-ton engine with ten cast-iron wheels under it, with their axles, axle-boxes, counterweights, coupling pins and coupling rods, has a greater proportion of its whole weight below the springs, and unrelieved by them, than an ordinary six-wheeled goods engine, weighing 35 tons.

Whatever economy in repairs may attach to the American engines is due, after allowing for the moderate working-speed, to three causes only, viz.:—First, the use of the bogie; Secondly, the use of chilled cast-iron bogie wheels, which can be renewed at a cost of from £2 to £2. 10*s.* each, after allowing for the value of the wheel taken out as old iron; and Thirdly, the use of steel or iron fire-boxes and iron tubes. It may be added, that there is no 'furrowing' of the thin iron employed for the boilers. The great number of wheels and coupling rods represent only a watchful care for the permanent way. As for the engine itself, the great multiplication of wheels, axles, journals, springs, compensating levers, and coupling rods, is anything but conducive to economy in repairs. Did English goods traffic admit of being worked at slower speeds permitting of heavier trains, could the prejudices against chilled wheels be overcome, and had English experience with steel fire-boxes proved more encouraging, a further considerable reduction in working expenses could be effected. There are other tests of locomotive economy than those already suggested. It is now the great aim of locomotive superintendents to keep their engines on the road and out of the shops as long as possible. From twelve to fifteen years ago the average mileage of American engines, taking the full stock of the leading lines, was not above 15,000 miles yearly—now it is probably not far short of 20,000 miles, and on some lines it may be even more. Of the four hundred and nine engines on the Pennsylvania Central Railroad in October, 1868, three-fourths of them being heavy goods engines, the average mileage for the month was 1,960, the average for September, with four hundred and two engines, having been 1,906. A large number of the goods engines averaged from 100 miles to 132 miles daily, while several of the passenger engines averaged 150 miles or more. In September forty-four engines, and in October

forty-eight, did no work, having come in for repairs; while in September forty-one, and in October forty-four, other engines received repairs in the month to an amount of £100 or more currency. The engine stock was of all ages between a month and eighteen years, one half of the number being less than ten years old. The engine-men have no 'shed days,' but must keep the road until their engines need repairs, and they must then take another, and the engine-report sheets of the line just named show that this may happen twice, thrice, and even four times a month. It is only a question whether the newer engines have really better constitutions than the older class. If not, they cannot under more constant work have the same expectation of life, in the sense understood by actuaries. The London and North Western Railway Report for the last half-year shows, for fifteen hundred and twenty-seven engines, besides one hundred and seventy-seven out of work and condemned, a mileage of 11,461,870, nearly equally divided between passengers and goods, and giving an average of 15,012 miles yearly.

There now remains the consideration of the carriage and wagon stock, with reference to its mechanical peculiarities and its commercial relation to traffic. The earlier American carriages were made upon the English model, but it was found, not only that a short wheel base was required for curves of 6 chains and 9 chains radius, but also that side buffers aggravated the difficulty. The bogie, already in use on the engines, was, therefore, adopted for the carriages, and it was soon discovered that the length of body could be considerably increased, and that the longer it was the steadier it became. But the long bodies precluded the use of side buffers, and so the central buffer with a loose coupling took their place. End doors afforded an obvious means of economy in the structure of the carriage, and left the whole depth of the body below the window-sills available for any combination of trussing, most effective for carrying a comparatively long span. It is an objection to long bodies with side doors, like those in use on the Metropolitan Railway, that having no vertical stiffness in their sides, they require unduly heavy under-framing. The end doors, with a continuous passage throughout the carriage, afforded obvious facilities for communication; and although partitions might be made across the carriage, it was soon found that passengers, with the easier habits of intercourse which prevail in America, preferred to share the whole carriage together. The central passage required an additional width of carriage, and from 9 feet to 9 feet 6 inches is a common outside width; while, in some cases, even on the narrow gauge, a width of more than 10 feet has been adopted. These widths allow seats for four passengers,

as well as for the longitudinal passage dividing the seats. The seats have reversible backs, so that the passenger may face either way, the carriages running in either direction without turning, the same as English carriages. It might be urged as an objection, that whereas, in English carriages, there is but one intermediate space between the seats of every compartment, or, in other words, that the seats occupy two-thirds of the floor area, the American carriages require a total amount of intermediate space equal to the total widths of the seats themselves. Taking the English compartments as 6 feet wide, then there are—less the space lost in partitions and upholstery—two seats, 2 feet each in depth and a space between them 2 feet wide. In the American carriages the seats along the whole length of the vehicle are spaced 3 feet from centre to centre, sometimes less. This division gives 18 inches width of seat and 18 inches intervening space, but as no space is lost in partitions, and but 2 inches or 3 inches in the padding of seat backs, and as each passenger has plenty of room to stretch his legs under the seat in front of him, the accommodation is by no means so contracted as it might appear to be. It is undeniable, however, that the seating is not so roomy and comfortable as in an English first-class carriage, and that, as compared with a second-class carriage, there is a certain loss of space. It is equally undeniable that such carriages could never answer for short traffic lines, where forty, fifty, or more passengers are to leave, and as many more to enter in a minute or a minute and a half. But without pursuing the question, it may be said, that the long body, with end doors and platforms, possesses obvious mechanical advantages. Its length gives steadiness, and the depth below the window-sills affords ample opportunity for providing vertical stiffness without undue increase of weight. There are no cross partitions; there are but two doors where English carriages would require, for the same number of seats, according to class, from twelve to twenty-six; there is much less sash and glazing required, while there is at the same time much more light; there is an important saving in respect of draw-springs, buffers, buffer-rods, and screw couplings, and there is every facility for applying breaks, as is always done in the States, to every wheel in the train, either from the platforms of the carriages or from the engine. It is an advantage of the long body, with its corresponding weight and number of wheels, that the application of the breaks, however suddenly, does not produce the jolting of which passengers complain so much when the same thing is attempted upon English carriages.

Passenger carriages upon the double bogie plan are made of various lengths, from 45 feet to 60 feet, exclusive of the additional 2 feet 6 inches at each end for platform and covering porch. They accommodate from sixty to eighty-four passengers, and weigh,

empty, 12 tons and upwards, or from 16 tons to 22 tons loaded. Here, again, the subdivision of weight is carried far beyond what is common in English practice. It is usual to provide six-wheel bogies or twelve wheels in all; and for the heavy sleeping cars, eight-wheel bogies, or sixteen wheels in all, are employed. The sleeping carriages known as Pullman's, are often 60 feet in length, and weigh 22 tons to 25 tons empty, but the weight is kept well below 2 tons per wheel. The first example of a so-called 'Palace Car,' upon the American plan, was made in 1855, by Messrs. Winans, of the Nicolai Railway, St. Petersburg, for the Emperor of Russia. It is 85 feet long and 10 feet 6 inches wide.

The eight-wheel bogie has been more or less employed in the States since 1849. In its original form, as embodied in a state saloon carriage, made in 1859, at Springfield, Massachusetts, for the late Viceroy of Egypt, each eight-wheel bogie was formed of two separate four-wheel bogies, connected by framing, the latter having a central socket for the pivot under the end of the main body of the carriage. The weight is sometimes taken, as far as this can be controlled, upon the centre of the bogie, side stops or bearings, with a slight allowance for vertical play, being introduced to preserve the equilibrium of the carriage. It should have been mentioned, that in the case of engine bogies, the whole weight resting upon them is received upon the flat bottom of a shallow central socket 10 inches in diameter, any tendency to roll being restrained by the support upon the driving and trailing axles, or rather the fastenings of the springs. In the case of tenders the forward bogie has no side stops to prevent rolling, the weight on the hind bogie being however supported equally upon the two sides. This form of support is known as that of the 'three-legged kettle,' and it is obvious, that it best secures the distribution of jolts to the whole frame of the vehicle, instead of at one or two points. In the case of the sixteen-wheel carriages, the motion, at high speeds, and over comparatively rough lines, is more like sailing than rolling.

The greatest improvement, unless it be Bissell's, made in the bogie, since its first introduction, is that of the 'swing beam,' introduced about twenty-five years ago, and for the last twenty years exclusively employed under all American passenger carriages, and for the last eight or nine years more or less extensively adopted for engine bogies. Instead of the weight being taken directly upon the bogie frame, it rests upon a series of springs, steel or india rubber, placed upon a transverse beam which is suspended by links from the cross timbers of the bogie frame—passenger carriage bogies being always made with timber frames. The transverse beam is thus free to swing endwise, or across the line, to an extent limited by stops, and which varies from $\frac{1}{2}$ inch to 1 inch

each way. The main framing of the bogie has also its own springs over the axles, the same as if no swing beam was employed. The double system of springs thus introduced, and the regulated allowance for swinging right and left, secures an ease of motion for which those who have not experienced it would hardly be prepared. It may be asserted, broadly, that these long double bogie carriages, thus supported, yet having neither screw couplings nor side buffers—having, too, small wheels, and but a limited range of play in the springs, and drawn over lines which are often in anything but first-class condition,—are, nevertheless, the easiest railway carriages to be found.

The oil-tight axle-box has now been in use for upwards of twenty years, and it has recently been adopted on the North London Railway. A leather collar surrounds the axle just inside the journal, while the outer end of the axle is enclosed by a closely-fitting cover, screwed to the face of the box. This cover is capable of ready removal when the box requires filling with oil, or when the brass wants renewal. By lifting the box, by means of a jack-screw, to the extent of $\frac{1}{2}$-inch or so, a distance piece or packing piece over the brass may be withdrawn, when the latter can be taken out and replaced without difficulty. The bottom of the box is filled with woollen waste, the requisite quantity of oil poured in, the box tightly closed, the number of the vehicle and the date noted; and, if a passenger carriage, it is not again oiled or examined for a month, nor, if a goods wagon, for two months. It is evident that the lubricating material is thus greatly economised, no attendance to the boxes during a journey is requisite, and a hot journal is almost unknown. It is considered beyond doubt, and Messrs. Guebhard and Dieudonné's experiments, already referred to, confirm the belief, that oil lubrication, with the perfect exclusion of dust, materially diminishes the tractive resistances, more especially in cold weather. It is a fact, however, that oil, tallow, and waste, cost, on an average, and when reduced to coin, a penny a train mile on most of the American lines. Of this comparatively high cost, however, much is accounted for by the high price and large consumption of tallow by the engines, especially in descending gradients without steam. On the more undulating portions of the Pennsylvania Central Railroad, a quart of oil, or its equivalent in melted tallow, serves only for about 13 or 14 miles' run of an engine; while, in the case of the heavier goods engines, but from 8 to 10 miles are made for the same quantity. Two gallons for a day's work are thought nothing remarkable, judging from the engine-report sheets, printed every month.

Another feature of American railway rolling stock is the use of breaks upon every wheel of every train, the engine wheels only

excepted. Since 1855 a system of continuous breaks, known as Loughridge's, has been more or less extensively employed on American lines. It is similar to that known in this country as Clark's, employed on the North London and other lines, with the exception that the friction wheel, instead of being pressed against the face of one of the wheels of the guard's van, is pressed against the flange of one of the trailing wheels of the engine. Another system of continuous breaks is that known as Creamer's, as applied, in 1863, to one of the trains of the South Eastern Railway. The breaks are put on, either in the ordinary manner by hand, from the end platforms of the carriages; or instantaneously, by the force given out by a stout coiled spring of sheet brass, previously wound up, and released by a pull at the bell rope or signal cord which runs through all American passenger trains. The force thus applied is only a little less than sufficient to lock the wheels, and taking the friction of the latter upon the rails as so little as one-eighth, it is possible to stop a train moving at 40 miles an hour, or $58\frac{2}{3}$ feet per second on a level, in a distance of 142 yards. Taking the friction of the wheels upon the rails at one-fifth, the stop would be made in rather less than 90 yards, and this or very nearly this quickness of stopping has been attained with Creamer's breaks, a result confirming Mr. Fairbairn's experiments made some years since on Fay's continuous break.

In comparing the cost of maintenance of American carriage and wagon stock with that on English lines, many considerations are to be regarded. To say that the cost, in 1867, on the 1,612 miles of railway in the State of Massachusetts, for a train mileage of nearly ten million miles, was 6·55 cents, currency, or about $2\frac{1}{2}d.$ coin, per train mile, does not permit of any accurate deductions. The American passenger trains are made up of carriages of but a single class; there are no through carriages from branch lines; the average number of passengers continuously carried over the whole distance made by a train is generally one half greater than in England, although the proportion of dead weight to live load is probably nearly as high as in this country; the speed is less, and there remains the fact that labour and nearly all materials are much dearer. On the other hand, there is a considerable saving in the use of chilled cast-iron wheels, such a thing as a wheel turning lathe for carriage or wagon stock being unknown in the States; the maintenance of buffer and draw springs costs much less; the maintenance of the carriage bodies is cheaper from their greater strength and simplicity of structure, and from the fact that there are no side doors to slam, and to this cause alone much of the repairs of English carriage stock is due. It may be added, also, that the cutting of seats, and the breaking or even scratching of carriage windows has not become a habit in

the States, and even from abuses like these the cost of carriage repairs is considerably swelled on English lines.

In closing this lengthy Paper, the Author finds his greatest difficulty in drawing from it conclusions of value to English engineers. Much that is peculiar to American practice is only externally so. Much that is essentially distinctive is, from circumstances of traffic, and from national habits, inadmissible, or inapplicable here. The extreme subdivision of the rolling weights, with the consequent multiplication of wheels, is not required on the heavier and smoother permanent way of English lines. For passenger engines the bogie is already largely employed here. For goods engines, however, working under the conditions of English climate, the adhesion due to the whole weight is generally requisite, and to throw any portion of that weight upon a bogie unconnected with the driving or working power, is to lessen, *pro tanto*, the effective duty of the engine. In all that has been said of the adhesion of American engines, it has been the object to show, that the maximum adhesion may be greater than is commonly admitted; but it is not the less intended to acknowledge the fact that adhesion is, from many causes, very variable. Instances of maximum adhesion can be found, of course, in one country as well as another, and the experience of many engineers of English lines will confirm a maximum adhesion of one-fourth the total weight.

While it is the wish of the Author not merely to disclaim, but sedulously to guard against professional preferences founded upon anything like national feeling, he cannot help repeating that the safety and economy of chilled cast-iron wheels entitle them to the best consideration of English engineers. One objection to these wheels, not referred to in the earlier portion of the Paper, is that, being almost necessarily of the disc form, their weight increases in a ratio nearly as the square of the diameter, and thus the largest railway carriage wheels yet employed in the States were but 3 feet, and this size was long ago discontinued in preference for 2 feet 9 inches. In the case of cast-iron spoked wheels, the chill is less hard opposite the ends of the spokes than elsewhere, and they thus soon show flat spots.

The success of steel fire-boxes and iron tubes, in American engines, gives new interest to the question of the further introduction of steel here.

The bogie tender, with the tank carried on three supports, that is, on the centre of the front bogie, and on the sides of the hind bogie, would be found much easier on the line than the ordinary six-wheel type. Sir Edward Watkin, when in Canada, in the winter of 1861-62, as Controller of the Grand Trunk Railway, had all the six-wheel tenders changed to double bogies, and to

this change he attributed a great diminution in the breaking of rails during that unusually severe period. There is no difficulty or danger, as is sometimes supposed, in applying breaks to the bogie tenders, even on the steepest inclines ever resorted to in practice.

As for carriage stock in which side doors are requisite, and where, therefore, the side framing between the windows and the sole plates has no strength of itself, there seems to be little advantage in long double-bogie carriages, beyond the facts that they offer less tractive resistance than ordinary carriages on curved lines, and that the longer they are the steadier they are.

If English engineers can anywhere introduce all the peculiarities of American practice, it appears to the Author that it must be on colonial and foreign lines, especially those in comparatively new districts. At home, a few only would probably be found both economical and acceptable to the general wants and habits of the public. It may be said, in conclusion, that if American railway practice be in any or in many respects more daring than that which prevails in England, failure, if not too often repeated, is regarded in the cousin country as a misfortune, where in this, unless it proceed from causes absolutely beyond prevision, it is rightly judged as a fault, a misdemeanour, or even a crime.

The communication is illustrated by a series of highly-coloured diagrams, executed by Mr. T. J. Ellis, Stud. Inst. C.E.

Mr. Colburn considered the subject already well worn—indeed almost threadbare. There were but few engineers who had studied the peculiarities of American rolling stock, with reference to their own practice, who were not already familiar with it in all its details. Many members of the Institution had visited the States, and had examined the question there for themselves. Beyond this, there was Captain Galton's ample report upon American railways, accompanied by what might almost be called working drawings of every variety of rolling stock.[1] After that came Mr. Neilson's Paper before the Institution of Engineers in Scotland;[2] and since then there had been almost continuous publications of everything of interest on the other side of the Atlantic with reference to this subject. Although he had not been in the States himself for eight years, he was in constant communication with railway engineers and managers there. Most of the statements in the Paper, which might lead to some discussion, were matters within his personal knowledge: in other cases he had derived his information from numerous printed and written documents sent to him by the managers of the leading lines in the States.

Mr. Hemans directed attention to the fact that, on a length of railway of 42,000 miles in America, the whole train service was performed by fifteen thousand locomotives; and as far as could be judged, those engines were smaller and less powerful than in England, where a length of 15,000 miles was served by ten thousand engines. Though a comparison of this nature would be modified by the quality of the service—such as an increased number of trains and greater speed—still it was almost as 2 to 1, and to that extent was in favour of the American engines.

He had calculated the resistance of the train, in the experiments made by Mr. Colburn on the Erie railroad, where a gross load of 1,572 tons had been taken up a gradient of 1 in 880. This was certainly a very extraordinary result. Taking the friction of the load at 8 lbs. per ton—which was the accepted ratio in England, —the friction of the engine at 15 lbs. per ton, of the tender at 12 lbs. per ton, and the effect of gravity on this gradient $2\frac{1}{2}$ lbs. per ton, and adding these to the load, a tractive force of 16,826 lbs. would be arrived at, which, when divided, would give a coefficient of adhesion of a little over $2\frac{1}{3}$. In other words, an engine on four wheels would be able to go up a less gradient than 1 in 3. On the Delaware division of the Erie railroad, the same engine had taken up a gradient 3 miles long, of 1 in 117, a gross load of 514 tons; this would produce a resistance of 14,156 lbs., or a co-

[1] *Vide* "Report to the Lords of the Committee of Privy Council for Trade and Foreign Plantations, on the Railways of the United States." By Captain Douglas Galton, R.E. Folio. Lond., 1857.

[2] *Vide* Trans. Inst. Civ. Eng. Scot., vol. i. p. 119.

efficient of adhesion of 2·8; so that the engine alone would run up a less gradient than 1 in 3. Assuming that there was some mistake, and that only $\frac{1}{4}$th of the adhesion given was available, the resistance would be 6 lbs. per ton, including the resistance of gravity; and if it were $\frac{1}{5}$th, the resistance would be 5·4 lbs. per ton only, of which nearly one-half would be due to gravity. Even if an error had crept into the report of the experiment, he thought there was still much to be considered with regard to the resistance of rolling stock in America, as there it seemed to be very much reduced, compared with the 8 lbs. per ton which was assumed in England. He believed the use of the double bogies to every wagon, which was apparently universal in America, of central buffers and drawbars, instead of side-coupling and close-coupled buffers, and moreover, of the closed oil-box, by which the dirt in the common railway grease was avoided,—had greatly reduced the resistance to railway trains, and ought to induce a careful study of improvements for rolling stock. He disapproved of the stereotyped make of English locomotives and rolling stock, and of the enormous weights placed upon a single pair of wheels. He had been informed of instances in which a weight of 18 tons had been put upon a single pair of wheels. These weights were very injurious to the permanent way. The practice of distributing the weight of the locomotive on a larger number of wheels was indispensable in America, where the permanent way was not very durable, and must lead to greater economy in wear and tear, and in the maintenance of the road. The limit to the distribution of weight by increasing the number of wheels must depend on the length of the wheel-base. Even if great weights could be drawn by locomotives without injury to the permanent way, he believed the present rolling stock and locomotives would require considerable modification. Mr. Fairlie's engine afforded the means of greatly diminishing the friction and weight upon individual wheels on a small wheel-base, while the tractive power of the locomotive was increased. It had been too much the habit to drive over all lines, whether main lines or small branches, the same stereotyped form of heavy locomotives and rolling stock. Where the traffic was enormous and ever-flowing, heavy engines and rolling stock might be suitable; but in such countries as Ireland, where the traffic was small, it was a wasteful expenditure to employ engines of 40 tons weight for drawing five or six carriages and a luggage-van, and but few passengers; and it was quite time to reduce the needless expenditure by which the profits had been swallowed up.

Mr. W. Bridges Adams remarked that a bogie was a short truck with a vertical pivot, allowing it to swivel beneath a superincumbent load. The earliest type was to be found in the timber-trucks of the railway. In carrying large sticks of timber, it was impossible to construct a wagon long enough for the purpose, so

the timber was placed on two trucks far apart; but it was soon found that, under such circumstances, the impediment to free running caused the vehicles to run off the line. And so saddles were placed in the centre of each truck, each with a vertical pivot, and the timber being laid on the saddles, the trucks were free to move round the curves. Thus, then, the bogie system resolved itself into vehicles with short wheel-bases instead of long ones. The drawing in Mr. Chapman's patent showed a bogie applied to the hind end of an engine, evidently originating in the perch-bolt and wheel-plate of the ordinary road-carriage, but with four wheels instead of two, and the guidance by the rails instead of the pole. But short wheel-bases 'wabbled,' though running with less resistance than long ones. The long bases, with greater steadiness, involved greater friction without being quite steady. So passenger carriages were screwed tightly together, and converted more or less into sledges, to increase the steadiness, but with the result of converting oscillation into vibration and grinding friction. Goods and coal trains, on the contrary, were loose-coupled, for the simple reason that otherwise their resistance would be so great as to overpower the haulage; and their sinuous motion showed how the wheels strove to follow the path of least friction over the irregular surfaces and incessant short curvatures of the rails. There was a proportion of length to breadth; *i.e.*, the distance between the axles, and the width of gauge, and the former must be more or less in excess of the latter. The earlier bogies were made with the wheels nearly close together; and the result commonly was, especially when running fast, that the bogie dragged or sledged, and the wheels recoiled from the contact with the outer rail, and took positions abnormal to the curves. To correct this, it became needful to lengthen the bogies. But under all conditions, whether a short or a long wheel-base, it was proved that, with rigidly fixed axles, even when truly parallel, and at a right angle with the central longitudinal line of the vehicle, the leading wheel-flange on curves got forced against the outer rail, and the trailing wheel-flange against the inner rail, and this placed the vehicle in a diagonal position. And the longer the vehicle, and the sharper the curve, the greater was the grinding and vibration. In England, there was a remarkable sample of vehicle, in which the breadth of the gauge exceeded the distance between the axles. It was the horse-box of the Great Western railway. Originally these vehicles were of great length, to contain many horses, which were expected to journey quietly side by side. But they would not stand transversely to the rails; and so the eight-wheel horse-boxes were cut in two, resulting in a 6-feet coupling with a 7-feet gauge. There was then nothing in the principle of the bogie other than that of a short truck, which, unsteady in itself, had the unsteadiness partially neu-

tralised by the long superincumbent load. And to neutralise this, as far as possible, the bogies had been gradually increased in length. The Bissell bogie, alluded to by Mr. Colburn, was a contrivance to place the pivot at a considerable distance behind or within the wheel-base. But in such cases the Bissell wheels ceased to have a guiding effect by their flanges, against the rails *per se*. The Bissell could only be used for an engine or carriage in which there were other and fixed wheels to maintain the gauge. This also was the case with the radial axle-box. The double bogie, or American carriage, was kept on the line of rails by its two pivots, which were always central between the two rails. But, if any rigid wheels were used on the centre of the vehicle with flanges to the rails, they could not run at all on curves. If made like certain early engines on the Bristol and Exeter railway—broad central wheels without flanges, and a four-wheel bogie at each end,—they would run well enough, but always subject to grinding, if short bogies were used. Other things being equal, it was quite clear that on a curved line every axle ought to point truly to the centre of the curve, with perfect freedom of movement from right to left, independently of the other axles. But in all bogies, the axles being rigidly parallel, this movement could not be attained. It was desirable, therefore, to bring the bogie wheels as closely together as possible, to minimise the evil. There was one mode of doing this, by making the bogie into a caster-moving body, like the movement that enabled a chair, or table, or bedstead to be moved round the room. The principle was, that the vertical axis should not be in a vertical line with the horizontal axis, but before or behind it. Suppose, therefore, a bogie with the axles 4 feet apart; if the pivot were placed as usual, equidistant from the two axles, the distance from the pivot to the leading axle would be 2 feet. But if the pivot were placed over the inner axle, the distance would be 4 feet, and the steadiness would, therefore, be equivalent to that of a bogie with the axles 8 feet apart. The inner wheels kept the gauge true to the pivot; the outer wheels were acted on by the rails against their flanges, and all four wheels were placed in positions nearly parallel to the rails, whether on curves or on straight lines. Or, the pivot being placed over the leading axle, the inner axle would conform the movement to the curves. But the position of the pivot near the inner axle would be the more favourable of the two, as being the centre, and leaving the moving circumference to be acted on against the curve of the rail, more easily than with the pivot over the leading axle.

With respect to the oil axle-boxes, there could be no doubt of their superiority to those used with grease or soap. In the old experiments of Messrs. Stephenson and Nicholas Wood, the result of repeated trials, on the fixed axles of a heavy grindstone, under the most favourable circumstances of lubrication, gave a frictional

resistance of 4 lbs. per ton of load. The same proportional sizes and lubrication, with rigidly fixed axles, applied to a wagon carefully constructed and set running down an incline, gave a result of 8 lbs. per ton of load at a moderate speed. Therefore what was called the rolling friction amounted to 4 lbs. per ton of load. Now what was rolling friction? If a polished steel cylinder were placed on an inclined plane of polished steel, the whole free from dust, there would be comparatively little friction, and the cylinder would advance in a straight line along the whole length of the incline. If the cylinder were changed into a cone, it would take a lateral movement or curvilinear and run off the incline. If it were formed into a double cone of largest diameter in the centre, and the incline were a groove made exactly to fit it, friction would immediately be evolved, and gradual wear. The rolling friction of the railway carriage was induced by the various bearings of the double cone of the wheels, unfitted to the lengths of the pathway they ran over, and by the friction of the wheel flanges against the rail edges. Under some circumstances this became so serious, that loaded trains had been known to stick fast on inclines of 1 in 75, and that single railway carriages, turned loose from a train, were unable to run down a gradient of 1 in 80, without being pushed; the friction, therefore, was changed from the normal 8 lbs. to 28 lbs. per ton, divided between the imperfections of lubrication and of rolling.

The question involved was so serious in its bearings on the commercial prosperity of railways that it could not long be ignored. It was a fact that goods and coal trains on main lines where passenger trains ran, only worked up to two-thirds the practicable power of the engine that hauled them. It was bad enough that they should be hauled at a wasteful rate of speed, but worse, that they were compelled to be shunted into sidings to get out of the way of the passenger trains. In this shunting the power of the engine could only deal with two-thirds of the haulage load. If drawing the train into the siding was difficult, it was far worse when propelling, for the train formed a zig-zag line, the wheels thrusting their flanges laterally against the rails. In all cases trains could be drawn more easily than they could be propelled. But the bogie-wagon, as it could be drawn more easily, could also be shunted more easily, and the caster-wagon before described would run with the minimum of friction in either direction.

It had been stated a short time back, when an application was about to be made to Parliament for a new coal line from the collieries to London, that by reason of better gradients larger loads of coal per train could be carried with the same engine power, and that, consequently, it could be sold cheaper. But it was said, in reply, that the measure of the engine power was not what could be

hauled, but what could be shunted. With rightly-constructed carriages this objection would cease.

The distinction between a caster-wagon on eight wheels and the American bogie-wagon consisted in the pivot of the caster-wagon being merely a guide that carried no load, whereas the American bogie carried the whole load on two centres requiring a strong cross framing; consequently the whole load was borne on two points of support. In the caster-wagon the whole load was borne on eight points of support, distributed over a great part of the length, commencing directly at the head-stock, and in a 40-feet wagon having only an unsupported space of 16 feet, while the American wagon had a length of 6 feet unsupported at each end, and of 28 feet unsupported in the centre. The central 16 feet might also be easily trussed as the American carriages were, and, therefore, the advantage claimed for the American system without side doors, in point of strength, ceased to exist. The solid side had reference solely to the bogie with only two supports. The free supports of the vehicles on the long swinging spring shackles gave facile movements to the caster arrangement on curves, restoring the axles to their rectangular position on straight lines by the action of gravity.

In reference to short journeys, there could be no doubt of the advantage of side doors for quick entrance and exit, and the end platforms of the American carriage involving 5 feet of length took up the space of a single body. There was an objection to side doors, for rapid change, by their projection over the platforms; but that simply arose from the fact that they were hinged doors, and not sliding doors as they ought to be.

For long journeys involving day and night travelling, no doubt the longer the carriage the steadier and the more economical it would be. And in point of width, the body inside might always be constructed double the width of the gauge. On the South Eastern and the Great Eastern railways there were passenger carriages 9 feet in width. On the broad gauge the carriages might be 14 feet wide. But for long traffic from London to Liverpool, or from the Land's End to Pentland Frith, there might be carriages, 50 feet long and 10 feet wide, on the 4 feet $8\frac{1}{2}$-inch gauge, settling the long-contested question of communication between guard and driver, by admitting of a free passage 2 feet wide through the interior, and 4-feet closed compartments on either side. But to allow this the platforms would require alteration and the tunnels would have to be removed.

Although, no doubt, the large wagon or carriage was the most economical, provided there was abundant traffic, still there were many circumstances which required four-wheel stock. The farther

the wheels could be kept apart in this stock, the better it would be, taking care only that due provision was made to avoid friction on curves. There was an arrangement of this kind with a caster movement, in which the side springs attached to each pair of axle-boxes at either end, were joined into a frame by cross-bars parallel to the axles, and by a central horizontal bar transverse to the axle. An eccentric pivot fixed to the upper frame and passing through this longitudinal bar was placed 7 inches to 8 inches behind the axle. The wagon was supported on brackets attached to the head-stock, and pendent from the springs by long swinging shackles and cross-bars; and thus on a curve the leading wheel pressing with the flange against the outer rail in front, and the trailing wheel behind doing the same, were thrust into their right positions parallel with the rails. The end of the horizontal bar also ran in a fork through which the traction-rod passed, and swaying to right and left in a horizontal slot of the headstock, kept the draught on the under frame in the central line between the two rails, with the wheels parallel to the rails. The buffers or bumpers were radial, to thrust truly on curves.

He might also refer to a system of self-acting continuous breaks. Gravitation levers were hinged direct from the axle-boxes, pressing each lever with a force of 112 lbs. on a pair of wheels. The weight at the lever end was 80 lbs., reduced by two moving sheaves to 20 lbs., and thence at the tender or guard's-van to 7 lbs. manual force. Thus the normal condition of the breaks was to be pressing on the wheels, when not lifted by the running cord passing over the wagon tops. And in case of ascending an incline with the not unfrequent breakings of a coupling, the instant the coupling broke, the lifting cord also broke, and the levers descended, pressing on the wheels, so that the severed portion of the train was arrested before it could reverse its movement and run back. The breaks also pressed on the portion of train still attached to the engine, and by retarding the speed, acted as a signal to the driver to look round. Mr. Colburn had pointed out that the breaks attached to bogie carriages did not annoy the passengers. This was because they were attached to the bogie but not to the body. But in that case every carriage required a separate breaksman. On the continuous self-acting plan just described, one breaksman either on the tender or the end van could manipulate the whole train.

For American engines only outside cylinders were used. In England both inside and outside cylinders had their advocates. One chief advantage of inside cylinders was, that they were enclosed in the lower part of the smoke-box, which kept them warm, and sometimes too warm, roasting by the hot embers. But against this was the disadvantage of the crank-axle, sometimes claimed to be an advantage, as lessening the leverage of the alternate piston

action and the disturbing force. This advantage was more apparent than real, for the position of the cranks necessarily elevated the boiler, giving a higher centre of gravity and more tendency to oscillation. But if the inside cranks were right in principle, their proportions were demonstrably wrong. A straight axle, measuring 4 feet 6 inches in length between the wheels, was about 7 inches in diameter. Now if the crank-axle were straightened out, it would be found to measure about 8 feet 6 inches in length. If, therefore, the diameter were one-eighth part of the length on the straight, it should bear the same proportion in the crank, which would be 13 inches. With two light engines on the Cork and Bandon railway, after the breakage of crank-axles of the ordinary proportions, he recommended an extraordinary proportion, and no subsequent breakage had taken place. The cylinders in that case were 8 inches in diameter, and the crank-axles 8 inches. The Fairfield Steam Carriage designed and constructed by Mr. Adams in 1849, for the Bristol and Exeter railway, under the direction of Mr. Gregory, the President, who was the earliest official recogniser of the light system of proportioning weight to load, and the first to give a practical order, had a crank-axle of ordinary proportions to 8-inch cylinders; but in that case the crank carried no load, being only needed to transfer the motion to a pair of outside side-rods, and this crank-axle did not break. Inside cylinders were also said to be advisable to prevent overhang, *i.e.*, they were placed between the wheels, and as close as possible to the leading axle. But this limited the size of the cylinders. On the American system outside cylinders were used without overhang, by the spreading of the four bogie-wheels equidistant round them.

With outside cylinders, any desirable diameter might be used, say 24 inches in diameter, with a length of stroke of 24 inches, or even 30 inches, connecting them efficiently by broad plates to the frame, and so to six or eight driving-wheels placed nearly close together. With the tank on the same frame on four or six wheels working radially, the cylinders might be balanced so as to prevent oscillation, with a total wheel-base of 30 feet, distributing the load over a large length of rail, carrying a water supply of 2,600 gallons, and rolling freely round curves of 3-chains' radius. With regard to keeping the cylinders warm, there was no reason why the smoke-box should not be efficiently extended round them to keep them as warm as might be needed. On ordinary gradients such an engine should command a train of 2,000 tons weight.

The generality of goods trains were uncertain as to their loads. Coal trains were always fully loaded except in returning. At present, these coal trains, by reason of their shunting operations, were limited in their load to about two-thirds of the engine-power, especially in haulage. If, therefore, the trains were so constructed that

the engines could shunt the full load, there would be one-third fewer trains needed, or one-third more coal could be hauled, economizing the sale price, and the same process could take place with goods transported in quantities.

Mr. G. Berkley believed that a certain amount of mobility, in all the parts between the earth and the weight of the engine resting on the springs, was desirable. He did not limit this to the bogie frame; it should be considered in relation to the permanent way, as well as to the parts of the engine, with a view to lessen the effects of blows, concussions, grinding and friction, and consequently the wear and tear of the engine and permanent way.

He had been quite prepared to hear that the Author had not been in America for a considerable time; and this might in some degree account for the extraordinary performances of engines recorded in the Paper, which he believed, were beyond those obtained in the regular practice of this or any other country. The adhesion of wheels on the rails undoubtedly varied considerably, according to the state of the rails, and to some extent to the material of the tires of the wheels and of the rails; but he had never found any well-authenticated statement to lead him to believe that the resistance of trains could be brought down to the amounts mentioned by Mr. Hemans, or referred to in the Paper; or that the adhesion of the engine on a rail would be sufficient to propel its own weight up a gradient of 1 in 3.

He had visited America two years ago, and on that occasion was much indebted to Mr. Colburn for facilities in getting access to the best information. He met with a most courteous reception and great liberality of treatment; and he was persuaded that all strangers who went to America to gain knowledge on scientific matters would be received in a similar manner.

Returning to the subject of American engines, he did not see any of the twelve-wheel class, of which he understood only one had been made; but a large number represented the English type of engine of the old stock. There was, in fact, little to say or much to gain by discussing them.

Then, as to the use of cast-iron wheels. He went to a foundry in Philadelphia belonging to Mr. Whitney, a name well known in America, and there saw wheels cast from iron selected and tested with great care. The wheels were cast in the ordinary way in which sleepers and chairs were cast in England, the outer rim being cast in an iron mould; afterwards they were removed, while at a bright red heat, to an annealing furnace, and there kept for about four days. There were probably on the 15,000 miles of railway in Great Britain and Ireland one million wheels. He did not admit that the price of wheels 33 inches in diameter was £3. 10*s.* each wheel. Messrs. Whitney and Sons had

furnished him with a list of prices in which these wheels, weighing 500 lbs., were quoted at $18\frac{3}{4}$ dollars, delivered on board ship at Philadelphia, which at the rate of exchange was £2. 10*s.* sterling instead of £3. 10*s.* The price of wrought-iron wheels, which was now low, would be for this size about £4 each. He had a letter, dated January 1867, from Mr. Brydges, the Managing Director of the Grand Trunk railway of Canada, and who was well known some years ago in connection with the South Western railway, in which it was stated that the price paid by the Grand Trunk Company for Whitney's cast-iron wheels was $14\frac{1}{2}$ dollars per wheel, or equal to about £3 sterling, in Canada. He was surprised to find the weight of the wrought-iron wheels was greater than that of the cast-iron in the proportion of nearly 6 to 5, while the cost of English wrought-iron wheels and of American cast-iron wheels was in the proportion of about 4 to $2\frac{1}{2}$. With respect to the efficiency of the cast-iron wheels, Mr. Brydges wrote as follows:—"I may say, in regard to the cast-iron wheels, that all the accidents that have arisen have been of an exceedingly mild nature." He might remark that the winters were severe, the temperature being sometimes from 20° to 40° below zero. Under this condition of temperature, the ground in which the sleepers were put would be as hard as rock, and the wheels in consequence would be severely tried, though the accidents arising were stated to have been trifling:—"And we have no instance on this line of any fatal accident occurring from the use of cast-iron wheels. The faults in the defective wheels are principally cracks, which are discovered by sounding, and therefore do no harm, or are flat places worn in the wheel itself, which wheel, of course, immediately upon being discovered, is removed. Our experience in regard to the use of these wheels is, that we consider them far superior to any wrought-iron wheels that have ever been imported from England. On one occasion several hundred cast-iron wheels were imported by this Company from Glasgow, but they turned out to be utterly useless, from not having been properly manufactured. This was before my connection with the Company. All the wheels we use are manufactured in this country; and the cost of them to us now, delivered in our works at Montreal, is 14·50 dollars per wheel—the weight of each wheel is about 500 lbs." Mr. Brydges stated that the number of wheels on the line, in January 1867, was thirty-six thousand, of which two thousand two hundred had been renewed in 1866. That would give a life to the wheels of about sixteen years; but from information subsequently received, he believed that they did not really last more than eight years on an average. He was sorry to say he could not give the mileage of the wheels which required renewal. The trains were run at good speed; and he had himself travelled on the line at an average rate of 30

miles, or 32 miles an hour. Mr. Brydges had also stated that he could not get these wheels from Glasgow. It appeared from the Paper that in America a quality of iron was obtainable that would bear a tensile strain of 15 tons to the inch. Two years ago a quality of iron, to be put into some sleepers, was specified by him to bear a tensile strain of 12 tons to the inch. Those sleepers, which were not easily cast, were supplied on board ship at about £4. 7*s.* per ton. As many as three hundred and eighty seven bars, 1 inch sectional area, were on the same number of days broken on a testing machine by means of dead-weights, of which the average breaking weight was 13·2 tons per square inch. If a quality of iron could be obtained that would bear so high a tensile strain at a cost of about £4. 7*s.* a ton, and if a proper annealing process were applied as in America, he thought these wheels might be satisfactorily made in this country for a considerably less sum than £2. 10*s.* per wheel, which was the price quoted in Philadelphia. He did not wish to suggest the use of these wheels with fast passenger trains, but it was worth consideration as applied to the large number of goods and mineral wagons.

The description in the Paper of American railway carriages left scarcely anything further to be said about them; but having travelled nearly 4,000 miles on American railways, he would give personal experience of them. These carriages were at one time largely introduced into various parts of Europe, but at present their use was in many cases abandoned; and his experience of American travelling did not lead him to recommend their adoption. The carriages on the Metropolitan railway were from 40 feet to 50 feet long; the side-doors were retained, and the framing was trussed below, so as to give stiffness and support to the long body. He would not refer to the objectionable events which sometimes happened in America from their being only one class of passengers. The sleeping-carriages in America were generally crowded; in one of them, about 50 feet long, there were fifty-six places for sleeping. On each side of the central passage there were two tiers of couches, 3 feet 9 inches wide, on each of which two persons were expected to lie. These sleeping-cars were provided by a company, distinct from the railway company, with a separate booking-office. The charge for a single sleeping-place was 75 cents, or 2*s.*, at the rate of exchange in September, 1866; but a passenger who objected to share his couch might take two places, or one whole couch, at a cost of about 5*s.*, or a state-room containing four places, for which the charge was about 10*s.* 6*d.*, and in this way a comfortable night's rest might be obtained. It was to be regretted that sleeping-carriages were not introduced on English lines where long night trains were run. He had directed the attention of several railway managers, five years ago, to a sleep-

ing-carriage designed for use in India, for which country a large number had since been built. These were about 24 feet long inside, accommodated twelve passengers, who had each a separate couch or bed, and afforded sufficient conveniences for washing, &c.

Mr. W. B. Lewis had recently received a letter from Mr. Brydges, to the effect that the cast-iron wheels of 33 inches in diameter weighed 550 lbs., which agreed with the weight mentioned in the Paper, and that the price, delivered free on board ship at Quebec, was £3 per wheel. Mr. Brydges also said that, though the speed on the Grand Trunk railway was not equal to that attained in this country, yet the line being a single one, the trains were often run at a rate of 40 miles to 46 miles per hour. He further stated that the stock of wheels was about forty thousand, and the renewals from five thousand to six thousand per annum. The maximum load on each wheel was $2\frac{1}{2}$ tons.

Mr. R. P. Brereton remarked that there were one or two points on which superiority for American practice was claimed by the Author of the Paper. In the first place, it was maintained that there was greater economy in the average cost of engine repairs, exclusive of what was due to renewals and heavy repairs equivalent to new engines. The cost, in English currency, was stated to be about 3*d.* per mile. It did not appear that this was any considerable economy, as on railways in this country with which he had been connected the locomotive repairs averaged $3\frac{3}{8}d.$ to $3\frac{3}{4}d.$ per mile, including all the renewals which the companies had effected. Assuming, however, that there was economy in the American system, it was attributed to three particular causes:—the use of the bogie, of cast-iron wheels, and of iron fire-boxes and iron tubes. He could not understand how the bogie contributed to economy in the repairs of the engines, as there were the bogie frame and double the number of wheels, axles and axle-boxes, subject to wear and tear. This multiplication of wearing parts must tend to add to rather than to diminish the cost of maintenance. He thought there might be some economy in the use of cast-iron wheels, but not in the use of iron fire-boxes and iron boiler-tubes. Although the first cost might be diminished by putting in iron tubes and fire-boxes, instead of copper and brass, yet the annual expenditure in repairs would not be reduced by it. No doubt bogies were advantageous in certain cases; but, on the other hand, they were not without their disadvantages. They had only been exceptionally employed in England. He was himself associated with those who he believed first introduced them on any large scale. Though the swivelling bogie-frame undoubtedly gave ease in passing over curves, yet, if it got off the rails, there would probably be a more serious accident than with an ordinary

six-wheel engine. He recollected a bogie engine, when running at no excessive speed, leaving the line at a considerable angle, and going over the parapet of a viaduct into the sea, by which several lives were lost. There was no question in this case that, with a six-wheel engine, the consequences would have been less disastrous.

Mr. W. A. Adams presumed the object of the Paper was to compare the system of rolling stock used on the American lines with that of the English lines. He could not but consider that the American form of carriage, resting on two short trucks with a limited wheel-base, and wheels 2 feet 9 inches in diameter, was a most inefficient machine; and he could only compare it to two short timber carriages. What would be said if an engineer in this country designed for the express mail between London and Aberdeen a railway carriage with a short wheel-base, and wheels of 2 feet 9 inches diameter, upon which was erected a very long body? It was generally acknowledged that the American passenger-cars were not easy of access, and that the long bodies without side doors were not so pleasant as the English carriages. The American system of carriages was adopted, in the first instance, for the Waterford and Limerick railway. He afterwards designed some bogie carriages for the Sirhowy railway in Monmouthshire, on the same plan, which worked very efficiently, at slow speeds, upon extremely steep gradients and sharp curves. The adoption of wheels of small diameter made of cast iron was a peculiar feature of the American system; and from all he had heard, the cast-iron wheels of 2 feet 9 inches in diameter were efficient as well as cheap. The Author of the Paper had given no information in reference to the wagons used for goods and mineral traffic. He should be glad to know whether the bogie system answered for goods wagons, especially those used in coal traffic. If they carried double the load of ordinary wagons, or from 15 tons to 20 tons each, it would be inconvenient to load a wagon with 20 tons and then partly unload it at a particular station: nor could they well be adopted for moderate loads. He thought the bogie system could hardly be used for an extensive coal traffic; and although it might be suited for goods traffic over long distances, he believed it could not be adapted to goods traffic generally.

Mr. Harrison, Vice-President, observed, that one of the most important points in the Paper requiring consideration was an experiment stated to have been made under Mr. Colburn's own direction. It had been referred to by Mr. Hemans, who had made some calculations which he had checked, and which he believed to be correct. They exhibited a state of things totally at variance with the experience of engineers in England. The Author of the Paper stated that an engine, having a weight of 17$\frac{7}{8}$ tons

upon the driving-wheels, took a load of 1,572 tons, including the engine and tender, up a gradient of 1 in 880. Now, in working out the problem, the first point to ascertain was the coefficient of friction. On looking into this question he was reminded of a circumstance that occurred some years ago, and though it was in the nature of an anecdote, he would ask to be allowed to state it. He was staying with the late Mr. Robert Stephenson at the time when Mr. Brunel met with difficulties in launching the 'Great Eastern' steam-ship. Mr. Brunel wrote and asked Mr. Stephenson to come down and look into the whole case. Mr. Stephenson had abstained from going down before from a generous feeling which could be readily appreciated. He accompanied Mr. Stephenson, and they passed the day with Mr. Brunel in examining the ship, upon which their views were exchanged in a most cordial manner. On their return in the evening, Mr. Stephenson and himself were discussing the subject of the difficulty in launching the ship; and the question naturally arose, What was the coefficient of friction of iron upon iron? Mr. Stephenson then took down from a bookcase a thick folio volume entirely in manuscript, and said that it, with similar volumes, contained the substance of all the lectures he had attended while a student at the University of Edinburgh, and that before going to bed, he had made a point of writing out the lectures at full length, accompanied by comments, and without difficulty a lecture containing the information required was referred to. Mr. Harrison had since examined the best authorities on the subject of the coefficient of friction or adhesion, and found, on referring to Leslie's "Elements," based on Coulomb's experiments, the coefficient given as $\frac{2}{7}$ths, in Whewell's "Mechanics" as $\frac{1}{4}$th, and in Moseley's "Mechanics" as $\frac{1}{6.25}$th, being based upon experiments made by Mr. Rennie. In Professor Rankine's work on steam-engines there was a case more to the point. It was there stated that, with the rails clean and dry, the coefficient of adhesion was equal to from $\frac{1}{5}$th to $\frac{1}{6}$th, in a greasy state of the rails to from $\frac{1}{14}$th to $\frac{1}{20}$th, and on an average an ordinary value of $\frac{1}{10}$th. Probably the great difference between the results of the experiments of Leslie and Whewell, and those of Moseley and Rankine, were due to the former having been made with large surfaces of iron upon iron; and to such extent that they were inapplicable to the question of the coefficient when applied to the small surface of a wheel acting upon a rail. The practical experience of engineers in England confirmed, as nearly as possible, the value assigned by Moseley and Rankine. It was found that in fair weather the coefficient of adhesion was $\frac{1}{6}$th, and that it varied for all weathers up to $\frac{1}{8}$th. He had himself always taken $\frac{1}{8}$th as a safe quantity, and had tested it by cases in every-day practice. In one instance, an engine with 17-inch cylinders, and 24-inch stroke, with six wheels

coupled, the weight of the engine being about 35 tons, took a gross load of 450 tons, or including the engine and tender 500 tons, up a gradient of 1 in 125 for a distance of 1½ mile. Working that out, he found that 500 tons divided by 125 gave for gravity about 9,000 lbs.; an allowance of 8 lbs. to the ton for the friction of the whole load gave 4,000 lbs. more; and the two together made 13,000 lbs. as the amount of the resistance. On the other hand, if he took the weight of the engine at 35 tons, and the coefficient of adhesion at $\frac{1}{6}$th of that weight, the result 13,000 lbs., was the actual daily working of an engine with such a load over a gradient of 1 in 125. Taking the weight of the engine, as given by the Author, at 40,040 lbs., in the first place he would assume the coefficient of adhesion given by Leslie and Whewell as a practical one, viz., $\frac{1}{4}$th, and this would give a tractive power from adhesion of 10,010 lbs., then the load at 1,572 tons, up a gradient of 1 in 880, would give 4,000 lbs. as due to gravity; and this deducted from the 10,010 lbs. gave 6,010 lbs., which in point of fact represented the friction of the engine and carriages, and when this was apportioned over the 1,572 tons, the result gave $3\frac{8}{10}$ lbs. or $\frac{1}{586}$th part of the load as due to friction. In this country so small an amount of friction was not known in general practice. But he would now take a value better known in English practice, viz., a coefficient of adhesion of $\frac{1}{6}$th of the load. With this he found that, at $\frac{1}{6}$th, the adhesive power would be only 6,673 lbs., and when the amount due to gravity of 4,000 lbs. was deducted, there remained 2,673 lbs. as due to the friction of 1,572 tons, or only 1·7 lb. per ton for friction, or $\frac{1}{1,300}$th part of the load. With such a state of things engineers in England were totally unacquainted. The friction was usually assumed to be 8 lbs. per ton, taking into account all the circumstances in which an ordinary train of wagons might be found. But whether it were 8 lbs. per ton, or 1 in 280, as compared with 1·7 lb. per ton, or 1 in 1,300, the question naturally arose, Was it possible that there was any mistake in the data of the Author's experiments? No doubt the atmosphere played an important part in regard to the coefficient of adhesion; but he could not bring himself to believe that there was anything in the atmosphere of America which could render the coefficient of adhesion different from what was found in England, under similar conditions of fair weather. Assuming the Author's statement to be correct, and that no great difference was caused by the atmosphere of the two countries, the question arose, Whether there was anything in the construction of American rolling stock, either the engines or the carriages, which could reduce the friction to less than 2 lbs. per ton? If American engineers had adopted any construction of rolling stock which would reduce the friction from 8 lbs. to below 2 lbs. to the ton, it was a matter of the

utmost importance to railway companies in England, and one which deserved thorough investigation.

Another important point, which the Author of the Paper had referred to, was the advantage of oil as a lubricator over the yellow grease commonly in use in England. Within the last few years, oil had been extensively used in the carriage stock of railways; and he spoke from experience as to the great advantage to be derived from it as a substitute for grease. He was not aware that in England any experiments had been made to test the difference in the friction of rolling stock with oil as compared with the yellow grease, though it was a subject which deserved experiment.

As regarded the adoption of cast-iron disc wheels, these would of necessity be required of larger diameter than those used in America, to adapt them to the fast travelling on English railways; and this would add considerably to their weight. He had used cast-iron wheels for more than thirty years as applied to ordinary coal-wagons; and he could speak, from that long experience, as to the gradual deterioration in the quality of the iron, till it had come to such a low ebb, that it had been found necessary totally to abandon it for wheels. He believed a cast-iron wheel, when made of the first quality of iron, was a most excellent wheel for special and slow traffic, and would last for many years; but such wheels were always liable to breakage, and the damage by the breaking of a cast-iron wheel was not always confined to the wheel itself, but might extend to the breaking up of a whole train.

He had investigated cases of the actual wear of a wrought-iron tire, because it was not the mere question of the wheel itself, which would last for almost an indefinite number of years, but the tire, which was substantially the measure of the life of the wheel. He found that carriage-wheels, 3 feet 6 inches in diameter, made of the best Yorkshire iron, would run from 40,000 miles to 45,000 miles without being turned. He also found that they would bear turning three times; and that the cost of turning on each occasion was from 1*s.* 10*d.* to 2*s.* per tire; therefore, practically, one of these tires would last a distance of from 160,000 miles to 180,000 miles. Deducting from the first cost of the tire itself, viz., £6. 5*s.*, the value of the old iron 19*s.*, there remained £5. 6*s.*; to which if there were added the cost of three times turning at 2*s.* per tire, or 6*s.*, the total cost would be £5. 12*s.*, or about 8*d.* per 1,000 miles travelled by the tire. He did not think it likely that the cast-iron disc wheels used in America would be adopted in England. Still there were many cases in the Colonies, where there were no facilities for getting new tires and turning them up, in which the use of cast-iron chilled wheels of the first quality of iron would be beneficial.

With regard to the printed tables produced by the Author, which showed the consumption of fuel, of oil, and of other materials

used in working the trains, he might state that on all the railways in England, similar returns were kept by the locomotive superintendents. The value of such documents depended entirely upon the use made of them. They were prepared every fortnight for the North Eastern railway, and were made useful in a variety of ways, being posted up in the locomotive sheds from which the engines ran. A standard of the consumption of fuel, oil, tallow, and all materials had been adopted, and when, in any case, it was found that the actual consumption exceeded the standard fixed on as a fair amount—not as a minimum—the engineman's name and the quantities were underlined with red ink. He believed every engineman was in the habit of examining the return when posted up. The mere posting up was unimportant; but every such case was inquired into by the locomotive superintendent, and if it was found for any continuous time—say two or three weeks consecutively—that an engineman had exceeded the standard, inquiry was made. Possibly the increased consumption resulted from a defective engine; it might, and often did, arise from the engineman, and if there was any doubt as to the capacity of the man, he was sometimes put upon an engine previously worked by another engineman with a small consumption of fuel, &c., and thus his ability was tested. By carrying out this system of rigid examination, from time to time, these returns were made to be of the greatest value and produced great economy.

Some remarks had been made on the subject of engines with outside cylinders. He had for many years under his charge a great number of locomotives with outside cylinders; but he could not agree with Mr. Adams that one objection generally urged against them was that the cylinders of these engines were not within the smoke-box, and did not derive the advantage of its heat. That was not an objection of serious importance; but a real and substantial objection to these engines was due to the fact that, with all the care taken in balancing the wheels, they could not be rendered perfectly safe engines at very high speeds. He had, therefore, gradually converted all these engines into others of a different form. As to economy in maintenance, construction, and working, they possessed, beyond question, great advantages; and if these engines could have been used with perfect safety at all speeds, he believed they would have been still in use. Mr. Adams had also taken exception to the shunting of heavy trains; and had stated, no doubt correctly, that the power of an engine in shunting a train backwards was not more than two-thirds the power in dragging it forwards; and on that foundation the limit of load of an engine was assumed to be only two-thirds of what it could draw on a level line. His experience differed from that, because there was no difficulty in arranging, wherever sidings were required into which to shunt

the trains, that a spot should be selected with favourable gradients for that purpose. He never found the limit of the load of an engine governed by the question of shunting, but by the maximum gradient it had to contend with on the line.

Mr. W. Bridges Adams, in answer to the statement that outside cylinders caused an engine to oscillate at high speeds, remarked that oscillation was a question of wheel base. The engines referred to, with a loose tender, had a wheel base not exceeding 13 feet, which, though not enough to keep the engine steady, was quite enough to cause great flange friction. He proposed to dispense with the ordinary coupling between the engine and tender, and to bolt them rigidly together, forming one frame with the wheel base in two groups, giving a total wheel base of 30 feet; the wheels under the tender being radial, to enable the conjoined frames to pass freely without flange friction, round curves of 3 chains' radius. Such an engine could be formed from the existing engine and tender, or be specially constructed with an enormous cylinder power, carrying 2,600 gallons of water, and running perfectly steady at any speed.

Mr. P. R. Hodge was present at the introduction of chilled wheels in the United States. A long series of experiments as to the proper mixture of metal, as well as a judicious arrangement of pattern to withstand all conditions, led to the construction of a chilled wheel that would not break. The Baltimore iron, with a mixture of New Jersey iron, was found best suited to the purpose. None of the imported iron was strong enough. The best chilled wheel introduced up to the time of his leaving the United States was that patented by Mr. H. R. Dunham, of New York. Its construction was simple and did away with one important objection to the old method of making chilled wheels, viz., that where the arm came in contact with the rim of the wheels it made a soft place, so that the chilled 'tread' of the wheel was soft and hard alternately, and after running some time caused a peculiar 'jigging' motion in the train. Mr. Dunham's wheel had a secondary rim to which the arms were attached, the annular space between each being cored out, so that the chilled tread of the wheel had nothing in contact with it to cause soft and hard places, and a uniform chill was obtained. He saw no objection to the use of chilled wheels for low speeds, but should not like to use them at high speeds. They would be most useful and economical in the Colonies, as the stocks could be replaced there at a low cost.

As to the question of the coefficient of adhesion, he would like to ask whether the experiment referred to by the Author was made in excessively hot weather, say with a temperature of 112° in the shade, when the rails would be expanded in their structural cha-

racter, as then he was satisfied the coefficient would be quite $\frac{1}{4}$th. As to the reduction of friction by the use of close oil-boxes, which were universally used in that country, he quite concurred with the Author. He was himself the inventor of the close oil-box in that form in the year 1849; and it was subsequently taken to the United States by Mr. Hughes, of the St. Petersburg and Moscow railway. He had tried to introduce this box on English railways, and in 1852 he applied them to some tenders on the London and North Western railway. These ran 21,800 miles with only a consumption of a pint of oil for the four boxes, which oil was afterwards taken from the lower chamber, and, after the dirt was precipitated, it was put back again, when the tenders ran the same distance over again. The use of oil as a lubricator instead of the dirty saponified compound—railway grease—was worthy of attention. The late Mr. Robert Stephenson had adopted close boxes for the Egyptian railway: to which the only objection was that the natives opened the boxes during the night to drink the oil. They were exclusively used in Austria, and wherever they were used in England answered admirably.

He exhibited a drawing, made by him in 1835, of the first engine with long connections, and eccentrics on the outside: and he had prepared the drawings for the first locomotive made in the United States. The history of the construction of locomotive engines in the United States was remarkable. Mr. W. Norris was induced by Colonel Long, of the United States Engineers, to aid him with the necessary funds for the construction of an engine intended to be equal, if not superior, to English engines. The front of the boiler was shaped like the bow of a boat, to cut the wind; the driving-wheels were 4 feet in diameter, with 9-inch cylinders, and 18-inch stroke. This engine, when finished, was placed on a siding in Broad Street, Philadelphia, not far from the Fairmount Waterworks. He went to hear Professor Johnson deliver an oration on the occasion of the engine being placed on a line of railway, but it would not go, and was pronounced a failure. Subsequently Mr. Norris employed Mr. David Sanno, who put a new boiler to the engine and so remodelled it as to enable it to take a load up the inclined plane on the Pennsylvania State Road, in the year 1835. The engines were built with long connecting-rods, because the rails were of flat iron, only $\frac{5}{8}$ inch thick by $1\frac{3}{4}$ inch wide, spiked down to longitudinal sleepers. Engines with short connecting-rods exerted a hammering action on the rails, which caused the ends of the rails to turn up, when the wheels coming in contact with them produced what was called in those days 'snakes,' which often penetrated the carriages. But as soon as the edge rails were introduced other arrangements superseded them. American engineers exhibited great energy and perseverance, and there

were numerous instances of persons pursuing the profession successfully when not originally brought up to it. Whatever might be said of American railways, it should not be forgotten that some of the best railways of that country were constructed at a less cost than what was paid for the engineering expenses alone of the Great Western railway of England.

Mr. W. Atkinson, who had visited the States within the last year, was enabled, through the kindness of Mr. James Livesey, to place in the library of the Institution a work in which were given the details of the experiments to which the Author had referred. They were made in the month of September, 1865. The case was there treated in detail. The frictional resistance of the engine and tender and cars was $4\frac{1}{2}$ lbs. per ton, and it occurred to him that in the course of the discussion the case was made more favourable than had been represented by the Author, because the per-centage of adhesion would be greater if the resistance of the train was taken at more than $4\frac{1}{2}$ lbs. per ton, as it was in England. Four other cases were cited, in which the results showed that the adhesion was not less than 36 per cent. of the insistent weight. The cast-iron chilled wheels, the bogie frame, and the large one-compartment carriage derived their origin almost exclusively from the extreme rigour of the American climate; for the permanent way was frozen so hard for many months, that, as had been pointed out, the English composite wheel was shaken to pieces, and nothing but the cast-iron wheel could resist the rigidity of the road. But this was not a reason for the adoption of the same wheel in England, until its effect on the permanent way had been tested, as the want of elasticity in the wheels must be to some extent injurious. The bogie frame was an arrangement peculiarly adapted to hard and rigid roads where the joints of the rails were uneven. A striking practical illustration of the effects of the rigour of the American climate was found in the fact that, on the Grand Trunk railway, in one year four thousand wrought-iron rails were broken, being at the rate of three rails for every mile of railway.

Mr. Berkley had given the cost of cast-iron wheels at £3 per wheel in America, and had stated that in England it would probably be £3. 10s. In Captain Galton's Report on the Railways of the United States it was stated that "these wheels, when made by the best makers, will run from 60,000 miles to 80,000 miles,"[1] or an average of 70,000 miles. Now the cost of wrought-iron wheels had been estimated at £4. 10s. each, and it was said, from experiments in Prussia with a weight of 2 tons on each axle, that wrought-iron tires would run 102,000 miles; but as they

[1] Page 14.

required returning several times, the cost of that must be added, which, at 2s. per wheel each time, would amount, say to 10s. in all for a wrought-iron tire. Thus the comparison lay between a wheel which cost £5 and one which cost £3. 10s.—the former capable of running 102,000 miles and the latter 70,000 miles, which gave 32,000 miles in favour of the former; and calculating the addition to be made to the original cost of the cast-iron wheel to give the 32,000 miles more, it appeared that the wrought-iron wheel was the more economical, for the old iron of the cast-iron wheel would be of little value, whereas the wrought-iron wheel would merely require a new tire to make it as good as new. This practically made the cast-iron wheel the dearer article of the two. At the same time he admitted that they were necessary in cold climates, and useful in such countries as South America, where there was no accumulated capital to invest in costly machinery, and where skilled labour for the turning of tires was scarce. Then, again, it had been suggested that the Scotch founders should be able to produce cast-iron wheels of equal quality to those made in America, as it was alleged that Scotch iron was nearly equal in quality to American. It so happened that the American manufacturers procured the iron for these wheels from various parts of the Continent, not only in the States but from the British provinces. The works which Mr. Berkley visited in Philadelphia were now receiving vast quantities of iron from the Acadian Ironworks, Nova Scotia; and there was this suggestive fact connected with that iron, viz., that though of the very best quality, it was of no use for making these wheels, as it would not chill unless produced in a particular way. There was found in the hills close to the mines a mineral called ankerite, which yielded iron and at the same time acted as a flux, and this put into the furnace with the ore produced the best iron for wheels: so that if there had been hitherto a want of success in Great Britain, there was this fact to fall back upon, viz., that iron suitable for the purpose could be obtained from Canada.

No mention had been made in the Paper of six-wheel bogies, but there was an advantage in having six wheels instead of four, as the motion of the carriage was rendered smoother. This bogie was being introduced into the best passenger cars, and he believed it was now generally adopted, as he did not see any eight-wheel bogies. It had been stated that experiments had been made to ascertain the difference in the resistance of trains when grease and oil were used, and that the difference was as between 8 lbs. and 4 lbs. per ton of train. In confirmation of this he might cite the well-known difference in the friction of sewing-machines from the use of different oils. If the oil was in a slight degree too viscid, the machine became almost useless; so that he

could understand that there would be great advantage from lubricating the axles of the rolling stock with oil. In regard to American rolling stock, Captain Galton in his Report stated that the weight of the passenger cars was 7 tons, and that they carried sixty passengers, but on one of his drawings the weight was given at 10 tons to carry fifty passengers; while the goods wagons weighed 6 tons and carried a load of 9 tons. Colonel Silas Seymour gave the weight as 7 tons to carry 10 tons. Mr. M'Cullum took the two at 17 tons; but Mr. Brydges stated, for the Grand Trunk railway, that the wagons weighed 10 tons and carried 10 tons. Then turning to the English rolling stock, it was stated that the wagons on the North London railway weighed $4\frac{1}{4}$ tons and carried a load of 8 tons, while the heavier wagons on the North Eastern railway weighed $5\frac{1}{4}$ tons and carried a load of 8 tons. It would appear from these figures that there was an advantage in favour of the English rolling stock.

No doubt great improvements had been recently made in the American sleeping-cars. Judging from one of those on the New Jersey Central line, he never wished to enter another; but in a journey from New York to Boston, he found the sleeping-cars lined with Utrecht velvet, the floor covered with rich carpet, and the furniture of the best description. On two occasions he had travelled in similar cars on the Grand Trunk line; and he believed Pullman's hotel-cars surpassed those which he had seen.

Mr. E. A. Cowper said, with reference to the close oil-box, and the coefficient of friction on American railways, that there seemed to be a wish for more exact facts, obtained by recent experience, of the friction of axle boxes in this country when fed with oil, and closed from all entrance of grit. He had applied to Mr. Beattie for permission to make experiments on the South Western railway, which was granted, and at the same time full information was furnished on the subject. Without going into all the details of the experiments, several of which were made in 1864, others in 1865, and some on that day, he would state, that the force required to start the carriage amounted in some cases to 4 lbs. per ton, and in others the friction was only 2·1 lbs. per ton of the gross load, to keep the carriage just in motion when the rails were level. In another case a force of 2 lbs. per ton of the gross load was sufficient to keep the carriage in motion. On that day experiments were made at a speed of 15 miles per hour, when the friction was 2·4 lbs. per ton; and at a speed of 25 miles per hour it was 2·8 lbs. per ton. The carriages were tried in different ways, on a level, on inclines, and with and against the wind. The results had been proved in several ways, and he was confident of their correctness. The experiments were made with ordinary carriages, and oil in close axle boxes, and the

results were ascertained with a dynamometer; in some cases one carriage only, and in others two carriages being towed. With respect to the quantity of oil used, he was informed that in 1864, one carriage ran 9,323 miles with a consumption of 1 pint of oil. The brass lost only 1 ounce in running 10,040 miles, and after 106,000 miles they were still in fair order. He was informed that brasses fitted with soft metal, where oil was used, might be put into an express train to run at once; whereas it was not safe to run carriages fitted with ordinary grease-boxes, and new brasses, in express trains at first, on account of heating. They were always used at first in trains running short distances only; but with oil, there was practically no fear of heating. He need only refer to the advantages of oil-boxes in the saving in friction, in grease, oil, and brasses, and in the saving of wages. The distance of 10,040 miles represented three years' ordinary work of the carriage, and it was actually performed by running the carriage to Exeter and back every day. The friction of 8 lbs. per ton, which was common with ordinary grease-boxes, ought, therefore, to become a thing of the past. He might add that the stock of wagons on the South Western railway was being fitted with close oil axle boxes with equally satisfactory results.

Major Palliser said, that, from experiments in chilling iron, it had been found possible to regulate the depth of the chill as desired, and that it was not necessary to use iron of any particular description, but by mixing different brands of the same iron together any required results could be obtained. The projectiles called chilled shot and chilled shells were not properly designated. They might more properly be termed refined iron shot and shell, because the chilling was carried through them. Excellent results could be obtained by shot chilled to a certain depth; but a slight mistake in the mixture of iron in such projectiles made a great difference in the kind of shot produced. It was considered too dangerous for ordinary manufacturing purposes to chill projectiles to a limited depth; therefore what were really refined iron shot were alone made. There was practically no difference in penetration between a shot chilled to the centre and one chilled to a limited depth, and therefore still tough. In one experiment French iron plates were fired at with chilled shot from the 7-inch rifle gun with charges of 15 lbs. of powder. The plates were supplied by different manufacturers, and one plate was better than the others. It stopped the first shot fired at it, which sunk into the plate until the base of the shot became flush with the surface of the plate. That shot remained quite unaltered, without a single crack in it, and might have been fired over again. The next shot, fired with a similar charge, struck the plate in a different place, went through it and broke up into a hundred pieces. This

showed that there was no difference in the penetrative power of hard tough shot and hard brittle shot, and that no increased penetration was gained by making the shot so tough that it would not break up. Shot with great penetrative powers was very brittle. A 7-inch shot placed on two steel bars 4 inches apart, and having itself a third bar on the top, was readily broken into two pieces under a heavy steam hammer; but if a similar shot chilled in for $\frac{1}{2}$ an inch was taken, it was found impossible to break it by the same means under the steam hammer, and the attempts to do so were discontinued for fear of injuring the hammer. The top steel bar was repeatedly cut in half without hurting the shot. The same iron cast in sand into a similar shot was flattened by the first blow of the hammer. In Prussia chilled iron was used for many purposes; such as ordinary blacksmiths' anvils and sledge-hammers, and it gave satisfactory results. It was generally believed that a class of iron, only to be obtained in certain places, was required to produce chilled articles: this however was not the case. He had always found, the richer the iron was in its nature, the less was the depth of the chill, while the poorer the iron the greater the depth it would chill, and that, by judiciously mixing the pig iron of any district, the amount of chilling could be regulated to any degree. He had met with some curious facts in his early experiments but which were accounted for afterwards: one of these was the liability of chilled projectiles to break up in cooling. Round shot, allowed to remain in the mould, contracted in cooling away from the upper part of the mould, and that the superior absorption of heat by the lower portion of the mould, which was in contact, broke the shot up into pieces. Also, when a large shot was allowed to cool in the open air, it sometimes flew to pieces with a loud report. This evil was overcome by burying the shot, as soon as they had become solidified, in hot sand, when they cooled gradually and uniformly. He believed that a somewhat similar practice was pursued with the chilled wheels in America.

Mr. W. Pole, agreed with Mr. Harrison as to the importance of the quality of cast iron, in considering the eligibility of wheels made of that material. The strength of iron quoted in the Paper seemed very high, but this was no doubt explained by the remark of Mr. Hodge, that the cast iron used for this purpose in America was exceptionally strong, much stronger, he believed, than the generality of English iron.

He had referred to some data on this point, which he would state. Tredgold's estimate of the tenacity of cast iron was, as was well known, based on an erroneous deduction from the transverse strain. The first reliable direct experiments were by Mr. Eaton Hodgkinson, who found that the tensile strength of various specimens of cast iron varied from 6 tons to 9·75 tons per square

inch; the mean being 7·37 tons. M. Navier had ascertained it to be from 5 tons to 9 tons, with a mean of 7·19 tons. The Iron Structures Commission of 1849 tested eighty-one specimens of seventeen different kinds of iron, which varied from 4·9 tons to 10·5 tons, with a mean of 6·8 tons. In 1856 an extensive series of experiments was tried at Woolwich, when eight hundred and fifty specimens of fifty-three kinds of iron by eighteen different makers gave a minimum strength of 4·2 tons, a maximum of 15·3 tons, and a mean of 10·4 tons; but as these samples were obtained expressly for trial, they did not correctly represent the marketable material, such as would be produced when large orders were given.

The valuable American experiments on cast iron used for cannon, showed that the initial strength of 5 tons of a certain iron might, by remelting, be raised to 11 tons, and further to 15½ tons.

No doubt it was possible in this country, by careful selection of the pig, and by judicious mixing, to produce a strong iron, perhaps even approaching the strength quoted from America; but under the ordinary commercial conditions, he was convinced that the manufacture of cast-iron wheels for railway stock in this country ought not to be resorted to without the greatest caution.

Mr. E. A. Cowper, in explanation of what he had previously said, stated that he had made further experiments on the South Western railway, relative to the adhesion of wheels to rails, in a dry, and in a wet state, for comparison, as far as circumstances would allow, with the experiments detailed in the Paper. As he could not readily get access to an incline of 1 in 880, he had taken one of 1 in 90 that offered. The weight of the engine was 31 tons, 1 qr. 14 lbs., and of the train of wagons 68 tons, 19 cwt., 2 qrs., 14 lbs., weights being added to bring up the coals exactly to 100 tons. A coupled engine with the driving-wheels 5 feet 6 inches in diameter was employed. The coupling-rods were taken off, and the weight on the driving-wheels was increased to 6 tons 13 cwt., to limit the power of the engine to the adhesion of those wheels only. The train was then taken up the incline. The force of gravity at 1 in 90 for that train was equal to 2,488 lbs., besides the friction of the 100 tons.

Friction of Wagon with White Metal Bearings and Close Oil-boxes.

Number of Wagon.	Weight.				Traction.	Traction per Ton.
	tons.	cwt.	qrs.	lbs.	lbs.	lbs.
4,548	6	3	2	0	$17\frac{1}{2}$	2·8
4,571	6	4	0	0	$16\frac{1}{4}$	2·6
4,618	6	2	2	0	18	2·9
4,607	6	4	0	0	14	2·2
..	..		..		25	4·0
..	..		..		16	2·6
					Average . .	2·85

The friction of the engine and wagons was found to be, on the average of a long series of experiments, 2·85 lbs. per ton, with white metal bearings and close oil-boxes, such as were in general use in the rolling stock of the South Western railway.

Then there was the question of adhesion. Taking the friction of the engine and train of wagons at 2·85 lbs. per ton, that would make the friction of the whole load of 100 tons equal to 285 lbs.; and adding 2,488 lbs. for gravity, the result was 2,773 lbs. The engine did show that force, because it took the train up the incline, and gained speed; and was purposely stopped on the incline and started again. The experiments were witnessed by Mr. Hemans and Mr. W. G. Beattie. As the weight on the driving-wheels was 6 tons 13 cwt., the adhesion was about $\frac{1}{5}$th of the weight. In another experiment, a pair of driving-wheels, 7 feet in diameter, with their axle, were placed on a level piece of railway; the wheels were then drawn along the rails without turning, the pull being at the level of the rail. The end of the rope was passed over a pulley to a scale which was weighted till the wheels slid along the rails. The wheels had no tendency to roll, because the pull was at the line of friction. During the experiment he several times rolled the wheels a little way along the rails without destroying the adhesion, or making them slide. The 7-feet wheels and axle weighed 2 tons, 15 cwt., 2 qrs., 5 lbs., and when the rails were dry, they first slid with a force of 1 ton, 3 qrs., 18 lbs., and then with 1 ton, 1 cwt., 1 qr., 10 lbs.; the coefficient of adhesion being respectively as 1 to 2·65 and as 1 to 2·60. He next tried the wheels wet, when 14 cwt. caused them to slide, so that the coefficient fell to about $\frac{1}{4}$th. Experiments with wheels 5 feet 6 inches in diameter gave nearly similar results.

ADHESION of a PAIR of DRIVING-WHEELS.

Diameter.		Weight.				Adhesion.				Ratio.	Remarks.
ft.	ins.	tons.	cwt.	qrs.	lbs.	tons.	cwt.	qrs.	lbs.		
7	0	2	15	2	5	1	0	3	18	2·65 : 1	Dry.
..		..		..		1	1	1	10	2·60 : 1	Dry.
..		..		..			14	0	0	3·96 : 1	Wet.
..		..		..			13	2	0	4·11 : 1	Wet.
5	6	2	6	1	6		12	3	20	3·58 : 1	Dry.
..		..		..			15	0	20	3·05 : 1	Dry.
..		..		..			6	3	2	6·84 : 1	Wet.
..		..		..			9	3	20	4·66 : 1	Wet.

With regard to an engine only giving an average of $\frac{1}{5}$th of the weight when pulling the load, it must be considered that the traction power varied in the revolution of the wheel. He had calculated the power of two cranks at right angles, and found the rotary power exceeded the average by 31 per cent. at one point. There must, therefore, be enough weight to give sufficient adhesion for the engine to exert its greatest power.

Mr. HEMANS would say, in corroboration of the experiments just referred to, which he had witnessed, that the general result proved that, under very favourable circumstances, a coefficient of adhesion of $\frac{1}{3}$rd, and under ordinarily favourable circumstances of $\frac{1}{5}$th, might be relied on.

Capt. TYLER said there were two great differences between English and American rolling stock, viz., the adoption of bogie trucks under the leading ends of the engines and under all the carriages and wagons, and the universal adoption of cast-iron wheels. It was an interesting subject of inquiry to ascertain how it was that, in America, bogie trucks were used under every car; and why nothing of the sort was used under carriages and wagons in England, and but rarely under engines; and why chilled cast-iron disc wheels were always used in America under the cars, and never in the United Kingdom under the carriages.

With regard to the question of bogie trucks, the Author of the Paper seemed to think that the bogie was introduced as a remedy for sharp curves. But the curves in America, as far as he had seen, were not sharper, as a general rule on many lines, than those in the United Kingdom: therefore some other cause for the universal adoption of bogie trucks in that country must be sought for. Certain engines sent to Canada some years ago were of the ordinary six-wheel coupled pattern of England, but they would not remain

on the rails, even when there were no sharp curves. Those engines were altered; bogie trucks were put under the leading ends, and they had since done good service. For this and other reasons he concluded that, though the original idea might have been to adapt the stock to sharp curves, the real reason why the adoption of bogie trucks became so universal was, because the roads were not generally in such good order as in England, and because it was found that the bogie system was, on that account, better adapted for them. In Canada, where the sleepers were unequally lifted by frost, and where the line was liable to fall into bad order during succeeding thaws, it was especially necessary to use bogie trucks instead of a more rigid system. In fact these trucks adapted themselves better to the sinuosities of a track which was not in good line, and the ups and downs of a track not in good level. Twenty-five freight engines had been recently sent out from this country to Canada, and they had been found to work well. They were somewhat similar to the engines used in America, with bogie trucks under the leading ends, and four coupled wheels. They had cylinders 16 inches in diameter, with a length of stroke of 26 inches; the driving-wheels were 5 feet in diameter, and the wheels in the bogie trucks 2 feet 6 inches in diameter. He found that the average cost of repairing engines there was 6·83 cents per train mile; the cost of fuel, 10·35 cents; and of oil and tallow, 0·41 cent. The total cost of working and repairing was 23·75 cents per train mile, as against rather more than half that amount, 8*d.*, in the United Kingdom. But the train loads were heavier, averaging 150 tons of freight, or one hundred and twenty passengers per train, against 58 tons of goods and seventy-three passengers per train for the United Kingdom. There were also difficulties of frost and snow, which were not met with in the same degree. By the last accounts he learnt that a depth of 15 feet of snow had fallen during the past spring, and there had been great difficulty in getting the traffic through at all during recent snow-storms, which had been heavier than for years past.

As with the engines, so with the cars. Bogie trucks were universally adopted with the cars also, because in practice it was found necessary to adopt them, more on account of the indifferent state of the roads, than for the curves they ran round. Not only was there less risk of the cars leaving the track when used with bogie trucks, but the concussions met with in running over a track not in good order were not so severe; they were less disagreeable to the passengers, and did less damage to the cars: the wheels were less injured by inequalities in the rails, and the rails were less affected by blows from the wheels. He remembered, however, an instance of a very sharp curve at Baltimore. The traffic between the two stations in that city

was drawn by horses, and the long bodies of the passenger cars appeared to be going in one direction, while the truck was twisting round and carrying them quite in another direction. It was a striking instance of how easily these long cars went round sharp curves.

But while there were certain advantages in the bogie system, it was not without its disadvantages. One of the greatest of these was the tendency which existed, particularly in the case of a bogie truck running under the leading end of an engine, to twist round when it got off the line. As a remedy against that state of things in Canada, the trailing end of the bogie frame was attached by a chain to the framing of the engine, so that it could not twist round beyond a certain distance when it got off the track. The same object was effected by means of stops, which had been adopted in the construction of the new engines above referred to.

He would next say a few words with regard to the universal adoption in America of cast-iron wheels, in place of the wrought-iron or steel tires, on the various descriptions of wheels in use in this country. The cast-iron wheels employed in Canada cost 14 dollars 50 cents each, or about £3 sterling; and as the discussion had turned on the cost of English wheels, and some valuable statistics had been given with respect to the wheels on the North Eastern railway, he had asked for similar information relative to the cost of wheels on other lines, and he had arranged in a table (A) the replies with which he had been favoured by the locomotive or carriage superintendents of the companies specified.

In another Table (B), which had been compiled for him in America in 1867, would be found interesting statistics of the cost per train mile of working several American railways.

It was difficult, however, to make any accurate comparisons, either as to the original cost of wheels, or the cost of maintenance, as there were so many circumstances to be taken into account. With regard to the comparative wear and tear of the American and English wheels, it was to be remembered that there were at least eight wheels under each American car, and there was the system of compensation above referred to, in the bogie truck, tending to diminish the blows upon each separate wheel; and the actual weight was probably rather less on each wheel in America, than in the United Kingdom. Though the cars were altogether heavier, yet, deducting the weight of the bogie trucks, and taking into account the woodwork and passengers only, there was probably less weight upon each wheel. He did not feel sanguine that the introduction of cast-iron wheels into England would lead to satisfactory results. The cast-iron wheel in America was a special manufacture, and the greatest care was taken with it, and

special qualities of iron were used for the purpose. At Baltimore, for instance, a mixture of two kinds of iron was used. If too much of the white iron was mixed with the grey, the chill went through: if there was too little, the chill did not go in far enough. So superior was the cast iron, and so much was this branch of manufacture attended to, that those who used these wheels, and who were also in the habit of using cast iron extensively for bridge-work, sometimes expressed themselves as preferring cast iron to wrought iron. He observed, also, cast-iron tires on some of the driving-wheels of the engines, which to the eye of an Englishman appeared very extraordinary. The Americans had also succeeded better with cast-iron guns than the English. But even if it were possible to make cast-iron wheels here equal to those used in America, it would not be desirable to use them. They were, at best, only a rough substitute, and hardly a cheap one, for good wrought-iron or steel tires, and should not be employed except in bogie trucks, in which the roughness they might occasion was of less importance. It was a question with reference to cars, whether the maintenance was on the whole cheaper than in England. In Canada the maintenance of cars cost 8·8 cents per train mile, or 0·7 cent per car mile, whereas in the United Kingdom, the average maintenance was only $2\frac{3}{4}d.$ per train mile.

But as an illustration of the difficulty of making comparisons which were worth recording, and of taking all the circumstances into account, he might point to the fact that, in Mr. Juland Danvers' report on Indian railways, the carriage maintenance on the different lines varied as much as from less than $1d.$ to more than $1s.$ per train mile. It was given, for instance, as $0{\cdot}93d.$ on the Calcutta and South Eastern railway, $5{\cdot}6d.$ on the Great Indian Peninsula railway, and $12{\cdot}92d.$ on the Bombay, Baroda, and Central India railway.

On the question of rolling stock in the United States, there was one specimen which he saw at Philadelphia of a novel character. It was a contrivance for carrying petroleum oil on the Pennsylvania Central railroad, and consisted of two large barrels, 4 feet or 5 feet in diameter, connected together by an upper framing. The barrels were provided with tires set to the proper gauge, and they were at the same time the wheels and the receptacles for the oil. He saw several examples of that kind of vehicle, but they were no longer in use.

There had lately been tried in Canada some interesting experiments deserving of notice,—viz., the employing cars on bogie trucks with adjustable axles, to suit different gauges. The gauge of the Grand Trunk railway was 5 feet 6 inches, and that of the American lines in immediate connection with it 4 feet $8\frac{1}{2}$ inches. A dozen of these cars had been running with considerable success, and as

TABLE A.

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Railway.	London and North Western.	Midland.	Great Northern.	Great Eastern.	Great Western.	South Eastern.	London, Chatham, and Dover.	London, Brighton, and South Coast.	London and South Western.
Description of Carriage Wheels principally used.	Mansell's wooden disc wheels.	Wrought-iron wheels with iron tires.	Mansell's patent wheels, 4 ft. diameter, wooden wheels with steel tires.	Mansell's patent wood wheel with east-iron boss, teak centres, and best Yorkshire or best crucible cast-steel tires. 3 ft. 6 in. diameter. 2 in. thick on tread.	(1.) Wrought-iron wheels with 8 spokes. (2.) Mansell's wood disc wheels, formerly Low Moor iron, now Bessemer steel.	Mansell's patent, 3 ft. 6 in. and 3 ft. 2 in. diameter.	Wrought-iron wheels 3 ft. 6 in. diameter, Kirtley's patent spokes, Patent Shaft Co.'s "B" tires, with Gibson's patent fastening.	Mansell's patent wood.	Wooden centre and iron tire; wheel 3 ft. 6 in. in diameter.
Average cost per Wheel with Tire.	£10. 10*s.*, including half of axle complete.	£9 per wheel and half axle.	£10. 16*s.* 10½*d.*, with half axle.	£7. 5*s.*, as above with steel tires.	Steel axle £3. 10*s.* Each wheel £7. 7*s.* 6*d.*	3 ft. 6 in. . £8. 16*s.* 3 ft. 2 in. . £7. 12*s.* (axle £2. 10*s.* to £3.)	£10. 10*s.*, with half axle.	£9. 10*s.*, with half axle.	£9, with half axle.
Average Mileage before turning up.	.. ..	30,000 before 1st turning. 30,000 before 2nd " 20,000 before renewal.	.. ..	.. ..	Low Moor 80,000. Steel . 120,000. (estimated.)	.. ..	25,000 to 30,000	.. ..	25,000.
Cost of turning up.	.. ..	.. .. *		Crucible cast steel, 1*s.* 1½*d.* each. Wrought iron, 9*d.* each.	.. ..	.. ..	1*s.* 8*d.* to 2*s.* per pair.	*s. d.* Taking wheels out . 4 4 Turning . . . . 2 9 Putting wheels under 4 4 Per pair . . 11 5	.. ..
Average total Mileage.	.. ..	80,000.	.. ..	.. ..	Low Moor tires . 550,000. Steel tires . . 880,000. (estimated.)	.. ..	.. ..	About 12 years; mileage not known.	100,000.
Cost of re-tireing, per wheel.	£4. 17*s.* 6*d.*	£4.	£6. 13*s.* 4*d.*	Labour, 2*s.* 6*d.* Material according to quality.	£3. 18*s.* 9*d.*	3 ft. 6 in. . £3. 8*s.* 6*d.* 3 ft. 2 in. . £2. 19*s.* 6*d.*	.. ..	£5. 6*s.* 6*d.* (per pair.)	*£. s. d.* Per pair, for labour and materials . 8 5 0 Deduct old tires . 1 2 6 Net cost . . 7 2 6
Total cost per carriage wheel per mile in maintenance.	.. ..	·012*d.*	.. ..	.. ..	Say £4. for 800,000 miles; or, ·0012*d.* per mile.	4*s.* per wheel per annum for carriage and wagon wheels.	.. ..	.. ..	0·0185*d.* (per pair.)
Relative friction per ton with oil or grease in axle-boxes.	No exact data, but much less with oil.	No appreciable difference with equal attention.	.. ..	.. ..	Oil better as lubricator, but grease more convenient; certain narrow gauge express trains have run 230 miles daily for 4 weeks without re-filling axle-boxes with grease.	.. ..	.. ..	.. ..	From recent experiments, average estimates— 3½ lbs. with oil; 8 lbs. with grease. In some cases only 2 lbs. with oil.
Miscellaneous.	.. ..	Axles to be renewed in 20 years. Wheels (wrought iron), no life period yet assignable.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..

* Cost of turning up 2*s.* 6*d.* per pair for steel, 1*s.* 2*d.* for iron tires per pair.

TABLE B.

Receipts and Expenses of Grand Trunk and certain other Railways (per Train Mile), as per their Reports for Periods as under.

To face page 414.

Name of Railway.	Miles of Road.	Period shown in Reports.	Train Mileage Earning Revenue.	Total Earnings.		Earnings per Mile of Railway.		Maintenance of Way.		Renewals of Way.		Locomotive Expenses.		Car Expenses.		Traffic Expenses.		General Charges.		Miscellaneous, including Taxes.		Working Expenses, Exclusive of Discount on Currency.		Per Centage of Working Expenses on Earnings.		Discount on Currency.		Total Expenses.		
				Dollars.	Per Train Mile.	Dollars.	Period.	Dollars.	Per Train Mile.	Dollars.	Per Train Mile.	Dollars.	Per Train Mile.	Dollars.	Per Train Mile.	Dollars.	Per Train Mile.	Dollars.	Per Train Mile.	Dollars.	Per Train Mile.	Dollars.	Per Train Mile.	Exclusive of Renewals.	Inclusive of Renewals and exclusive of Discount on Currency.	Dollars.	Per Train Mile.	Dollars.	Per Train Mile.	Per-centage on Earnings of Expenses, including Discount on Currency.
Grand Trunk	1,337	½ year	1866, June 30	2,349,222	3,102,135	1·32	2,252	½ year	304,687	·13	127,924	·06	683,363	·29	218,000	·09	629,309	·27	71,607	·03	56,339	·02	2,091,229	·89	63·29	67·41	69,419	·03	2,160,648	·92	69·65
Ditto	..	..	Dec. 31	2,509,040	3,500,927	1·35	2,542	..	311,763	·13	352,307	·14	690,149	·27	199,331	·09	637,293	·25	81,500	·03	92,858	·03	2,365,291	·94	57·49	67·56	300,898	·12	2,666,999	1·06	76·15
Ditto	..	..	1867, June 30	2,294,045	2,961,389	1·29	2,153	..	321,378	·14	157,535	·07	761,574	·33	220,557	·09	650,008	·29	69,959	·03	118,182	·05	2,299,193	1·00	70·53	75 86	104,898	·05	2,404,091	1·05	81·09
Great Western	345	..	1866, July 31	704,951	1,670,057	2·37	4,841	..	107,913	·15	123,324	·18	198,356	·28	90,660	·13	257,228	·37	38,250	·05	39,369	·05	855,300	1·21	43·83	51·22	193,724	·28	1,049,024	1·49	62·81
Michigan, Southern	523	year	Feb. 28	1,970,340	4,086,445	2·38	8,980	year.	917,743	·46	..	..	624,419	·32	232,426	·12	844,054	·43	109,868	·05	258,137	·13	2,986,647	1·51	..	63·72	..	..	2,986,647	1·51	63·72
Nova Scotia	93	..	Sept. 30	162,829	199,739	1·23	2,147	..	58,578	·37	..	..	53,973	·33	16,765	·09	30,410	·18	5,845	·04	..	..	165,571	1·01	..	82·89	..	..	165,571	1·01	82·89
New York, Central	691	..	..	6,204,775	14,596,785	2·35	21,124	..	3,249,404	·52	..	..	3,764,256	·61	1,207,467	·19	1,964,533	·32	440,582	·09	769,431	·12	11,395,673	1·83	..	78·06	..	..	11,395,673	1·83	78·06
Erie	699	..	Dec. 31	6,709,139	14,596,413	2·18	20,882	..	2,912,126	·44	..	..	3,872,097	·57	1,196,895	·18	2,673,456	·40	198,506	·03	578,481	·08	11,431,621	1·70	..	78·32	..	..	11,431 621	1·70	78 32
Illinois, Central	708	..	..	3,094,223	6,546,741	2·11	9,246	..	1,381,666	·45	..	..	967,248	·32	356,956	·11	1,053,624	·34	1,469,964	·04	464,836	·15	4,371,294	1·41	..	66 77	..	..	4,371,294	1·41	66 77
Northern Railway of Canada	96	..	..	345,068	512,875	1·48	5,342	..	118,525	·34	..	..	90,389	·26	29,366	·04	64,361	·19	22,609	·06	11,762	·03	337,012	·97	..	65·71	..	..	337,012	·97	65·71
Cincinnatti, Harlem, & Dayton	60	..	1867, Mar. 31	(mileage not given.)	1,301,536	..	21,692	..	245,330	..	..	..	245,354	..	68,117	..	244,053	..	40,169	..	75,011	..	917,974	..	..	70·53	..	..	917,974	..	70·53
Chicago, Burlington, & Quincy	393	..	April 30	1,837,312	6,116,862	3·34	15,641	..	976,069	·54	..	..	857,556	·46	364,245	·19	697,799	·38	198,905	·11	258,825	·14	3,353,399	1·82	..	54·55	..	..	3,353,399	1·82	54·55

The Expenditure of Foreign Roads, as shown above, has been classified, to accord as nearly as possible with the Grand Trunk Returns for the purpose of comparison. The Totals (Receipts and Expenditure) will be found to agree with their published Reports.

many as two hundred were being constructed at Boston. It could not, of course, be expected that such a speculation would be entered into without the expectation of considerable profit; and the proprietors were paid as much as 3 cents per car mile for the use of those vehicles, they providing the cars and taking all risks in regard to the peculiar arrangements required. The use of these cars would, if they were successful, dispense with the necessity for laying down a third rail on some portions of the system, and enable narrow-gauge cars to run on other parts of the system where such a measure could not be contemplated. In Ohio the gauge of the railways was 4 feet 10 inches, and in the adjacent States it was 4 feet 8½ inches; and to meet that difficulty a wider tread had been adopted for the tires. One particular in which the Americans surpassed, was in the construction and fitting-up of special cars for sleeping and refreshments. They had not only sleeping-cars, but also 'hotel' cars, 'drawing-room' cars, and 'palisade' cars, many being fitted up with great taste and at great cost. He had travelled with Mr. Pullman, whose name some of those cars bore, on one occasion, between Chicago and Detroit, and riding in a director's car in front of one of those sleeping-cars, he had a good opportunity of watching the various operations going on in them. The passengers had their dinners or suppers cooked in the car, the beds were prepared as desired, and then they lay down for a comfortable night's rest. This was an agreeable mode of travelling, which he had often wished to see introduced into the United Kingdom, and he thought that even the commoner descriptions of sleeping-cars were excellent. The means of ventilation, adopted in Mr. Pullman's and other cars, by which all cooking odours were avoided, were admirable, and were effected without draught or other annoyance to the travellers. Fresh air was admitted through cold water round the stove in summer, and hot water in winter. He had asked Mr. Pullman what justified such an enormous expense in constructing these cars, some of them, as he was informed, having cost upwards of £5,000. The reply received was, that if cars of an ordinary kind had been constructed, everybody would have followed the example; but by turning them out in the most costly manner, there was a better chance of retaining the monopoly; and this had been so far successful, that the advertising of these cars as running upon certain lines brought an augmentation of traffic to them. An objection in the eyes of some English companies, as regarded these expensive and luxurious cars, would undoubtedly be their great cost. A still more valid objection would be their great weight; and this objection could not be better expressed than in the words of the American engine-driver, who "guessed they might as well hook on to the depôt itself."

Sir Charles Fox observed that the greatest load brought upon

the driving-wheel of a locomotive in America was about 4 tons. In the United Kingdom the load was much larger; and he had no doubt that was the reason why the rails were so short-lived. There was a certain limit in an iron rail, still larger in a steel rail, beyond which, if too heavy a load were placed, the rail got worn and damaged. In the same way a stone step might be many times trodden on with a small force, and on each occasion only a very minute portion of the stone would be removed; but if it were stamped on with a force beyond what was necessary to produce simple abrasion, it would be quickly destroyed. Therefore, in his opinion, it was of the greatest importance, in order to conduct the traffic on a railway at a small cost, to keep quite within that limit, which he believed to be about 4 tons. In the Act entitled, "An Act for the Regulation of Railways," introduced by the Board of Trade, and passed last session, the weight of 4 tons was assumed as the maximum weight for what were therein termed light railways. He had tried to get the limit fixed at 3 tons, but was met by the difficulty of its not being sufficient to take in the existing rolling stock, which in some cases brought nearly 4 tons on to the rails by each wheel. On a line of light railway in India, constructed by Mr. Berkley and himself, the load was limited to 3 tons; but it could be extended to 4 tons without injury to the rails, which weighed 36 lbs. to the yard. They had become worn, but had not got laminated in the four years the railway had been open. In introducing light railways in England, it was expedient to make use of the existing rolling stock, with the exception of the locomotives. The heaviest vehicle on any railway was the Great Northern goods truck, weighing about 5 tons 10 cwt., and capable of carrying 10 tons of coal, in all 15 tons 10 cwt., on four wheels. Acting upon the principle of assuming a weight of only 4 tons on a rail, the Government had sanctioned the introduction of clauses into a Public Act for the construction and use of what were called light railways. Assuming that an engine travelling on a main line with a train of twenty carriages, stopped at a station to drop two or three intended to go on to the branch line. Hitherto all branch lines had been constructed of sufficient strength, to bear the heaviest locomotives used on the main line; but under the new law, lighter engines could be specially constructed capable of dragging three or even four carriages, but not twenty. And inasmuch as the main line engine was expected to run to the terminus of the main line, it seldom happened that such an engine had to traverse the branch line; therefore an engine under any circumstances must be specially provided for the branch service, and on that account it was better to have a line, on which the traffic was small, made strong enough only to carry that lighter traffic. When he proposed this clause, with respect to placing the small

weight on the rail, to the Board of Trade, he found the introduction of some such principle favourably entertained; but there were great difficulties to overcome. The question had been raised whether, if a branch line were permitted to be made as a light railway, the main line engines would not be allowed to run upon it and damage it at some time or other. He at first proposed to place at the junction with the main line an apparatus, like a weigh-bridge, capable of carrying an engine of 20 tons' weight, but not one of 30 tons. But it had been pointed out that although this, if kept in working order, might answer the purpose, yet if an engineman chose to run on to the branch line, it would be rendered perfectly useless. At last it was resolved that, inasmuch as engines with small wheels only were required for the branches, and as by their use the centre of gravity would be placed at least 1 foot nearer to the ground than in those on the main line, the soffits of the overbridges on the branch (or, if there were no bridge, then a girder) should be placed 1 foot lower than those on the main line; when if a man driving the main line engine chose to pass on to the branch, the chimney of the locomotive would be knocked off. With this proviso the clauses were introduced.

The almost universal adoption in America of wheels not more than 2 feet 9 inches in diameter, for all vehicles except locomotives, was worthy of note. He believed wheels in England were far too large. The grease-boxes, for many years, were very defective, admitting sand and dirt, which, from the viscid nature of the grease, were held in suspension, and brought to the surface of the journal, which caused great friction; the wheels were, therefore, made large to reduce the friction. On the Cape Town railway, to which he was Engineer, the traffic was worked at first with ordinary grease-boxes; but it was found that some of the fine sand, continually blown from the sea-shore over the railway, entered the grease-boxes, and was more or less brought into contact with the bearing surfaces of the journals, causing serious friction. This was, in a great measure, averted by the adoption of close oil-boxes, in which the oil was supplied to the bottom of the box, and raised therefrom to the journal by capillary attraction, while the sand fell to the bottom of the oil. In this way the journals were lubricated with pure oil, and the traction necessary for moving vehicles fitted with those boxes was thereby materially lessened. When a wheel was in motion on a level its weight was comparatively of no importance, but in starting and stopping or passing up a gradient, it was a matter of moment. He believed that, though a large wheel had a few advantages in respect of friction, other circumstances counterbalanced them. For carriages and wagons he advocated the exclusive use of wheels of 2 feet 9 inches in diameter, as he believed they would be safer, lighter, and cheaper. On the Indian Tramway

trains with wheels only 2 feet in diameter ran, on many occasions, 40 miles an hour, stoppages included; and none of the driving-wheels were more than 3 feet 3 inches in diameter, and there had never been any complaint in reference to the size of those wheels.

It had been mentioned in the Paper that the wheels had no cone on the tires. He disapproved of conical wheels, because, on the majority of railways, curves formed a small proportion of the length of the line; and it was better to run a little worse on curves (even if such were the case, which, however, he did not believe), and well on straight lines than the converse. With a conical wheel on straight lines the motion was steady only so long as the flanges kept equidistant from the rails, which in practice seldom or never happened, and that was the cause of the sinuous motion of a train in running over straight lines. He had constructed railways, one of which was 120 miles long, on which cylindrical wheels, not conical, were used; the effect of the cone was done away with, and the trains ran over them quite steadily. The American iron wheels were made of excellent iron, and were well cast; but he was surprised to find the tensile strength of the iron given at 15 tons to the square inch. He had never met with cast iron of such tensile strength; and he should like to know by what means the result was arrived at. Some years ago a contract was given out by the War Department for a number of cast-iron columns and girders for barracks in Jamaica; and the specification stated that the iron to be used in these castings was to have a tensile strength of 10 tons to the square inch. Up to this time he had always been accustomed to consider the strength of ordinary cast iron as 7 tons, according to Hodgkinson's tables; but this specification was so rigid that, though his firm had been in the habit of making large quantities of castings, they determined not to tender in this instance. Many tenders were sent in, and the contract was given to a Staffordshire house. The order was executed, and the War Department wrote a complimentary letter in approval of the manner in which the work had been done. He subsequently inquired how the required tensile quality of iron was obtained, seeing that the contract was executed under the supervision of an officer, representing the Government, who had the power to go into the foundry at any time, take any ladle full of metal intended for this work, and cast therefrom a bar 3 feet long and 1 inch square; and if it broke below the required standard, he had a right to reject the castings. The explanation given was that, upon the receipt of the order, a number of trial bars were cast of the best mixture of iron very carefully worked. Every morning some of these bars were placed in the sand, and by their side holes of the same dimensions were made, close to them: everything was thus got in readiness for the inspecting officer

when he made his appearance. Whenever requested by him, a ladleful of metal was taken, and a portion of its contents poured into the holes prepared in the sand; and care was taken to insure the officer always taking away with him the right bar. The testing having been made, a piece of metal was cut from the fractured end of the bar, labelled, and sent to London, and might probably now be found in the archives of the War Department. It should be added that what most astonished the officer was the wonderful uniformity of the iron used throughout the contract. He should like to know, whether the testing in the case mentioned in the Paper was conducted on the same priniciple. He had tried many experiments upon the tensile strength of charcoal iron, but had never got any iron up to a standard higher than 10 tons. If, however, cast iron in a state of fusion was exposed to the action of the atmosphere, so that the oxygen might absorb a portion of its carbon, and was thus brought into a state analogous to steel, the tensile strength would be increased. How that was to be done at the price stated by Mr. Berkley—only a few pence per ton more than ordinary cast iron—in the case of iron sleepers of which the material was said to be equal to a tensile strength of 12 tons, he could not conceive. If cast iron could be made of such strength as 15 tons to the sectional inch, he would recommend all merchandise wagons, at least, to be fitted with cast-iron wheels. If it were cast and broken up and recast a good many times, then it might be worked up to that tensile strength; but, as ordinary cast iron, he did not think there was any such in England.

He considered the use of oil in a well-constructed axle box, made as tight as possible, was one of the best methods that could be devised for reducing the amount of power necessary for the traction of a train. Though some trains were run at a fair speed in America, he had found it to be generally 25 miles per hour; and from observations he had made, he was inclined to believe that 25 miles per hour was the cheapest rate at which trains could be run. A locomotive had to deal with four sources of retardation;—first, axle friction, which was a fixed quantity; whether the engine went quickly or slowly the same quantity of coke was consumed. Next came gravitation, which also could not be altered; for whether a load were taken up an incline, or lifted vertically to a similar height, the same amount of power would be required. In the third place, there was what was called gauge concussion, which increased rapidly as high speeds were attained; in what ratio he could not say—some said as the square of the velocity, but he believed it was even more. Then, again, there was the resistance of the atmosphere, which increased as the square of the velocity. At 25 miles per hour the resistance of the atmosphere was almost inappreciable,

and to any one on the engine it only seemed an agreeable breeze; but as the speed increased, it became necessary to hold on. Therefore, there was a limit to speed up to which the engine might be run without any important addition to the consumption of fuel, and yet the smallest quantity of rolling stock be used. If, instead of 20 miles an hour, the speed were reduced to 10 miles, the same amount of merchandise would not be conveyed in a given time as at the higher speed. On several lines, where coal had been usually carried at a rate of 12 miles an hour, it had been found more economical to increase the speed to 25 miles per hour.

Mr. W. Lloyd had been in competition with American engineers on American soil, and could state that they knew much more than English engineers gave them credit for. He had great pleasure in acknowledging the many advantages he had gained from professional contact with them.

Ten years ago the Author of the Paper, in a work on European Railways published in New York,[1] devoted attention to the English system as it then existed, and pointed out many advantages which the Americans would gain by the adoption of some of its features. Amongst others, that the English railways were far better constructed than the American lines. It was stated that the cost of maintenance of American lines was 150 per cent. greater than that of English railways for the same mileage, which was attributed to imperfection in construction; and that an expenditure of £600 per mile on a single track would reduce the operating expenses of American roads quite 9*d.* per mile run, which was equal to an annual saving of £200 per mile of road. The working expenses of the two systems were also compared, and some of the items stood as follows:—

	Per Train Mile run.	
	England, 1856.	State of New York, 1855.
	Cents.	Cents.
Wages: enginemen and stokers . . .	3·25	5·50
Coke and coal	6·50	17·90
Repairs of engines	5·50	9·80
Ditto cars and wagons	7·50	8·70
	22·75	41·90

Maintenance of way and engines and working were stated to amount to 6·62 mills per ton per mile for the railways of England, and 11·48 mills per ton per mile for those of New York. He would next refer to the rolling stock. He had worked both

[1] Vide "The Permanent Way and Coal-burning Locomotive Boilers of European Railways: &c." by Z. Colburn and A. L. Holley. Folio. Plates. New York, 1858.

English and American locomotives conjointly on more than one railway in South America. Although at first sight very different in appearance, because the crank-axles and the side-bearings were done away with, and the crank was placed outside, yet, intrinsically, there was not much to say about the American locomotive, which to all intents might bear the venerated name of Stephenson. As to the bogie truck, it was quite as much an English as an American invention. But the chief difference in the working of these engines was in the consumption of fuel. He had invariably found great economy in the consumption of fuel in the English engines. On the Chilian lines—

			lbs.	
English engines in	1,324	miles consumed	38·4	per mile.
American „	„ 1,492	„	42·1	„

On a gradient of 1 in 44, in the course of six months—

			lbs.	
English engines in	10,073	miles consumed	42·77	per mile.
American „	„ 1,049	„	59·14	„

American engines burnt 18 per cent. more fuel than English, as proved by the experiments of Mr. Evans. It was stated at the time that the English engines were a failure. He was prepared with some further statistics of the comparative consumption of fuel, viz., the—

Railways.	lbs.
Lima	38—40 per mile.
Great Indian Peninsula	42·99
Chilian	31·97
United States	50—70

It must therefore be admitted, as far as consumption of fuel was concerned, that the English locomotive had decidedly the advantage.

There were some minor points of difference in American locomotives which it might be well to accept. The head light was very bright, and if there was any advantage in having a brilliant head light, the Americans were far in advance in that respect. The whistle, also, of the locomotive was very powerful, and the oil-boxes were superior to anything of the kind in England, and he had known carriages run 10,000 miles in Chili without having the oil-boxes touched. If that was compared with the difficulty and trouble experienced in England in keeping the boxes stocked with grease, the advantage would appear manifest.

In the economical working of railways, the weight of the different descriptions of carriages was an important consideration. He found that the first-class American carriages were superior to the English in this respect, but that the second and third-class carriages were inferior.

	lbs.	Passengers.		lbs. Dead Weight.	
American 1st class weighed empty	25,310	for 60 =	about	422	per passenger.
English ,, ,,	15,680	,, 30 =	,,	522	,,
American 2nd class ,,	23,390	,, 60 =	,,	390	,,
English ,, ,,	15,680	,, 48 =	,,	327	,,
American 3rd class ,,	22,500	,, 60 =	,,	375	,,
English ,, ,,	17,920	,, 60 =	,,	298	,,

The American wagons had rather the advantage over the English. American platform wagons, weighing 14,060 lbs., carried a weight of 10 tons; which was 1,406 lbs. dead weight per ton. English open wagons, weighing 12,400 lbs., carried a load of 8 tons, being 1,550 lbs. dead weight per ton. These carriages and wagons were used on a line of 5 feet 6 inches gauge. A short line 4 miles long, in Mexico, was worked with American carriages in the first instance; but the number of first-class passengers was so disproportionate to the number of the second class, that it became necessary to alter the system. A dummy train was, therefore, adopted: that was, a small engine in front of a long carriage; by which the working expenses were reduced to 40 per cent. from about 90 per cent. That system would be found advantageous in working branch lines in England. There were, he considered, a few social disadvantages in the American system of carriages, for which reason he should be sorry to see them adopted on English lines. He had mentioned that there was too much dead weight for the few passengers of a class. A heavy carriage was required to accommodate them; and the constant vertical motion was disagreeable in a long transit; while, in case of collision, the long carriages were more liable to injury. He had seen collisions in which they had collapsed from being exposed to a pressure from both ends. There was no rigidity in such a train, and consequently there was greater risk in case of collision. There were other inconveniences with long carriages in one compartment, affording accommodation for sixty passengers. Draughts from open windows were an annoyance to some, though agreeable to others; and the ingress and egress of a large number of people along the carriage at each station was inconvenient: but these were minor matters, which need not be enlarged on.

He had always thought a bogie truck a clumsy contrivance, because, as had been observed, it was not required on a straight line, and the greater part of all lines were straight. Bogie trucks were, undoubtedly, useful on curves and bad lines; but it should be an object with English engineers to make good lines, and avoid curves as much as possible. He had laid out sharp curves, but from necessity, not from choice. It had been recently pointed out, that the working expenses of English railways had steadily increased from 40 per cent. of the receipts in 1845, to upwards of 50 per

cent. in 1867. If that were the case, he thought the importance of such Papers as the one under discussion could not be overrated. It was through the economical working of railways alone that railway enterprise could be resuscitated in England. Unless great economy was introduced both in the construction and the working of railways, there would be but few more railways to make.

Mr. G. K. Radford gave the particulars of the locomotive expenses on the Eastern Division of the Pittsburg, Fort Wayne, and Chicago railway, for the year 1865, as recorded in the Table (p. 424).

Mr. Colburn observed, in reply, that it had been his wish that the discussion should turn entirely upon the mechanical and commercial questions which the Paper might raise, and be wholly free from any tendency towards national bias. In this hope he had not been disappointed. It was not so easy for professional gentlemen to gather the complete evidence of what was passing in a distant country, even when in frequent communication with it, nor even where a visit, more or less hurried, was paid to it. There was evidence that English engineers and English railway managers, on going to Canada to take charge of lines chiefly owned in England, had, notwithstanding their natural and habitual preference for English practice, unquestionably adopted the peculiarities of the railway practice of the United States. Why had they done so? Bogie trucks and chilled wheels were not more necessary in Canada than in England; nor was the question of safety, did the use of chilled wheels affect it, less regarded in Canada than here. But these Anglo-Canadian engineers and managers asserted that the bogies drew more easily than carriages with rigidly rectangular wheel bases, and that chilled wheels were equally as safe as, and less expensive in maintenance than, wrought-iron wheels. Upon the latter point he had seen the original letters of the late Mr. Ross, of Mr. Brydges, and of Mr. Eaton of the Grand Trunk railway, and of Mr. Swinyard, of the Great Western railway of Canada, and he could therefore attest the fidelity of the printed copies he possessed.

[Copy.]

Montreal, August 9, 1859.

My dear Sir,—I send you herewith the information required in your note of the 3rd inst., which I obtained from our locomotive superintendent.

Our experience in cast and wrought-iron wheels has induced our giving a decided preference to *the former*.

I have myself been instrumental in the introduction of the English pattern in wheels, and after two or three years' trials have been obliged to abandon them altogether.

I am, my dear Sir, yours sincerely,

Mr. George E. Gray, Albany, N. Y. Alex. M. Ross.

PITTSBURG, FORT WAYNE, AND CHICAGO RAILWAY.

ABSTRACT of LOCOMOTIVE EXPENSES on the EASTERN DIVISION, for the Year 1865.
Length, 188 miles. 88 of the Locomotives burn Coal, the rest burn Wood.

MONTH.	Number of Engines.	Number at Work.	Goods	Passengers.	Fuel and Ballast.	Mileage of Goods Engines.	Average Mileage.	Mileage of Passenger Engines.	Average Mileage.	Miles run to 1 Ton (2,000 lb.) Coal.	Price per Ton (2,000 lb.).	Miles run to a Quart of Oil.	Fuel per Mile.	Stores per Mile.	Drivers, &c., per Mile.	Repairs per Mile.	Total per Mile.
											Dollars.		Cents.	Cents.	Cents.	Cents.	Cents.
January .	100	86	58	23	8	125,093	2,157	61,601	2,678	44·00	4·00	20·60	10·00	2·50	7·90	9·50	29·90
February	98	89	59	22	8	121,052	2,051	55,843	2,538	35·80	5·00	19·30	14·00	2·60	7·90	8·80	33·30
March .	99	88	59	23	6	132,940	2,252	64,424	2,801	39·00	5·00	20·60	12·80	2·40	7·10	7·60	29·90
April .	98	87	56	23	8	127,040	2,268	59,056	2,567	36·20	5·00	18·80	13·50	2·70	7·60	8·00	31·80
May . .	98	90	60	25	5	120,410	2,006	58,587	2,343	39·50	4·00	19·50	9·80	2·50	7·80	8·20	28·30
June . .	98	84	54	24	6	107,498	1,991	53,520	2,230	41·52	3·50	20·66	7·26	2·57	7·76	7·26	24·85
July . .	98	85	49	28	8	119,766	2,448	62,714	2,239	52·41	3·50	23·90	6·61	1·91	7·04	6·85	22·41
August .	98	89	58	24	7	146,923	2,533	57,785	2,407	45·30	3·50	21·80	7·59	2·62	6·85	6·60	23·66
September	98	89	57	23	9	140,810	2,470	55,765	2,424	44·82	3·50	21·69	7·80	2·60	7·00	8·30	25·70
October .	98	93	62	23	8	149,787	2,416	56,248	2,415	40·20	3·50	24·50	8·80	2·50	7·20	7·60	26·10
November	98	88	56	23	9	139,053	2,483	57,164	2,483	40·71	3·00	22·39	7·40	2·50	7·40	9·10	26·40
December	98	88	56	23	9	143,878	2,569	57,151	2,484	40·85	3·00	21·57	7·40	2·40	7·50	9·02	26·32
Average .	98	88	57	24	7·6		2,303		2,470	41·70	3·87	21·27	9·41	2·48	7·42	8·07	27·38
			Totals . .			1,574,250		699,858									
							27,636 per Annum.		29,640 per Annum.	46·70 to Ton of 2,240 lbs.	s. d. 13 3 per Ton of 2,240 lbs.		d. 3·37	d. ·91	d. 2·72	d. 2·96	d. 10

Exchange calculated at $6·53 to £ sterling.
2·72 cents. = 1*d*.

Average of all Engines at Work and under Repair, 24,908 per annum.

Average Wages per Week.

	£.	s.	d.
Engine Drivers .	3	9	0
Firemen, &c. .	1	17	0
Mechanics . .	3	0	0
Labourers . .	1	14	6

Engines, average weight, 24 tons.
4 wheels coupled, average 15 tons on driving-wheels.
Heaviest engine, 30·4 tons = 4 tons on a driving-wheel.
Passenger carriages, average weight, Empty . . . . 14 tons.
" " " " Full . . . . 17 "

Freight carriages, average, Empty . . . . . 7½ tons.
" " " Full . . . . . 15¾ "
Average number of Freight Carriages in a Train . . . 16
" weight of Loaded Freight Train, and Engine . 262 tons.
" " " Passenger " " 80 "

At the time the above was written, Mr. Ross was chief engineer of the Grand Trunk railway of Canada.

[Copy.]

New York Central Railroad,
Chief Engineer's Office, September 1, 1866.

W. W. Evans, Esq., Chief Engineer.

Dear Sir,—In reply to your inquiries as to the relative merits of cast and wrought-iron car wheels, I would say that experience has demonstrated the superiority of cast-iron wheels in all particulars. They are more durable and equally safe. The average time a cast wheel will wear under the heavy traffic of this railroad is four years. We have about forty thousand wheels in use, chiefly made from Salisbury iron. Old wheels are used in small proportions in making new ones. The cast-iron wheel will save more than its cost in the increased time it can be used. Failures are of rare occurrence: our respectable makers of late years have no broken wheels returned on them as defective. Trains are often run, when behind time or from other causes, at the rate of 60 miles an hour for many miles together, and this over far worse tracks than are ever found in England or France. This company have tried the best wrought-iron wheels made in England, and under the most favourable circumstances, and in all cases have found the cast-iron wheels the cheapest, the most durable, and equally safe.

I remain very truly yours,
George E. Gray,
Late Chief Engineer.

[Copy.]

Grand Trunk Railway of Canada,
Managing Director's Office,
Montreal, Jan. 19, 1867.

My dear Sir,—In reply to your letter of the 14th, I have the pleasure to send you a copy of a letter from our mechanical superintendent, which will give you all the information you ask for.

We are entirely abandoning the use of wrought-iron wheels, and hope soon to have nothing on the line but those made of cast iron.

Yours faithfully,
C. J. Brydges.

Geo. E. Gray, Esq., Off. C. P. R. R. of Cal.
54, William Street, New York.

[Copy.]

Grand Trunk Railway of Canada,
Montreal, Jan. 19, 1867.

C. J. Brydges, Esq.

Dear Sir,—In reply to Mr. Gray's letter of the 14th inst., I beg to state as follows:—

1. Our car wheels, with the exception of about two per cent., are made of cast iron, and the small proportion that are of wrought are being replaced by cast wheels whenever any of the former wear out or break down.

This, of course, implies that for car purposes we prefer cast-iron wheels to wrought-iron wheels.

2. Until recently our car wheels were made at Toronto and Buffalo Lane, Three Rivers, C.E., and the Portland Company. At present they are made at Montreal, of the best cold-blast charcoal iron, which is made at Three Rivers. On the American section of the road they are supplied by the Portland Company, and Washburn, of Worcester.

3. The winter being severe, we are able to and do experience some few failures of cast-iron wheels.

4. We have accidents from the wrought-iron wheels arising out of the same cause as is attributed to the failure of the chilled wheels by the severity of the winter.

5. I can only estimate the mileage of the wrought-iron wheels, and I consider that 20,000 may be taken as a fair average of miles run before requiring turning up.

Yours truly,
RICHARD EATON.

[Copy.]

Great Western Railway,
Hamilton, Canada West, Feb. 6, 1867.

DEAR SIR,—It affords me much pleasure to send you the information required in your favour of the 14th of January. It has been handed to me by my mechanical superintendent.

Yours faithfully,
THOS. SWINYARD, Vice President.

Geo. E. Gray, Esq., 54 William Street, New York.

Questions.	*Answers.*
1. What kind of car wheels are in use on your railway; if of cast or wrought iron, which is preferred?	We have cast and wrought-iron wheels in use, but cast-iron wheels are much preferred, both in point of safety and economy.
2. If of cast iron, what is the weight and diameter?	Weight, 480 lbs.; diameter, 33 inches.
3. Do you have accidents from the use of cast-iron wheels?	We have not yet had an accident from the use of cast-iron wheels.
4. What is the average mileage of the same?	Average mile run, about 160,000.
5. If of wrought iron, do you have accidents from breakage?	Very seldom, until the tires are worn thin, when they generally get loose and break.
6. What is the average mileage of the wrought-iron wheels before requiring turning off?	Wrought-iron wheels require turning off about once in every six months.

W. A. ROBINSON.

As some misapprehension apparently existed both as to the weight and the price of chilled wheels, he would give a Table, sent by Mr. Edward H. Williams, General Manager of the Pennsylvania Central railroad, in December last. The prices in dollars were reduced in his communication from currency to gold, and

the prices had been converted from gold dollars into English money:—

Class of Wheels.	Diameter.		Weight.	Cost.		
	Ft.	Ins.	lbs.	£.	*s.*	*d.*
Passenger	2	9	560 to 580	3 3 to 3	0 to 7	0
Goods	2	2	382	2	0	0
„	2	4	432	2	5	0
„	2	6	490	2	10	0
„	2	9	542	2	18	6
Tender	2	2	370	1	17	0
„	2	4	397	2	2	0
„	2	6	452	2	6	6
„	2	9	558	2	18	0

As for the bogie system, it was to be hoped that it might receive a fair trial here; and it was to be remembered that it had been almost universally adopted in the States, after long and full trial of ordinary four-wheel carriages and wagons, which were at one time exclusively employed, and, in the case of wagons, were in extensive use as lately as ten years or fifteen years ago. The bogies were worked at almost all speeds, and were quite steady at the highest speeds attained in the States, and the speeds were occasionally, although not regularly, as high as in England. Mr. Williams, of the Pennsylvania railroad, in the course of a lengthy communication, wrote as follows:—

"The use of the truck, with swing motion and equalising beams, is not only considered to be a necessity on roads with short curves, but is thought to be desirable and of manifest advantage on the straightest and best constructed roads in America."

It formed no part of his purpose to enlarge upon the social, as distinguished from the mechanical and commercial, aspects of American railway travelling. But he might observe, that the sleeping-cars were in great request upon long journeys by night, and were, indeed, most popular with the wealthier and more respectable classes. These carriages might suggest some sort of accommodation for which many passengers would gladly pay, at least if the parliamentary limitation of fares to certain *maxima* per mile did not prevent such payment, and the consequent adoption of such carriages at all.

Some doubts appeared to have arisen as to the adhesion of driving-wheels upon American lines. It was his object to show that the maximum adhesion, under the most favourable circumstances, might be greater than English engineers were in the habit of estimating, and also that these favourable circumstances were possibly, indeed actually, more general in the American climate

than in the United Kingdom. Any physical result accurately observed abroad, could, under the same conditions, be repeated here, and he had testimony from several engineers in England showing that locomotive adhesion occasionally rose to one-fourth of the adhesion weight. The fact was, however, that maximum adhesion was seldom experimented upon by railway men. In other words, practice soon taught them what was about the minimum adhesion, and the necessities of railway service compelled them to regulate the loads of their engines, by the lower instead of the higher standard. So it was also in the States. But there the conditions of climate, although as variable, were very differently variable from what they were here. That condition of rails known as 'greasy' was unusual, and the term itself was scarcely ever heard. The rails were generally quite dry, or quite wet, and the wheels and rails then acted upon each other precisely as they would act here, when in the same condition. Mr. George Rennie's experiments showed that the friction between iron and iron when dry was even greater than had been suggested in the Paper, and another fact might be taken as tending to confirm, if confirmation were needed, the instances cited in the Paper. American goods engines drew, in regular work, as heavy, if not heavier trains, than English goods engines, but at a lower speed. They were worked to as high a pressure, often had larger cylinders, and almost always smaller driving-wheels. Yet their total weight was generally less than that of English goods engines; and in by very far the majority of cases from one-fifth to one-fourth, or even one-third of their weight, was carried upon a bogie, as weight unnecessary for adhesion. It was only where the cylinders were very large, and the wheels very small, that the whole weight was employed for adhesion, and all-coupled tank engines were quite exceptional.

The engine 'Reuben Wells' was worked only upon a gradient $1\frac{1}{4}$ mile long, and rising 1 in $16\frac{1}{2}$, being more than twice as steep as the steepest inclines on the Great Indian Peninsula railway. The speed was not much above 5 miles or 6 miles an hour, and the working was reported as most satisfactory. Instead of from 8 tons to 9 tons per wheel, as in the case of the twin four-wheel engines of 34 tons weight, made in 1856, for the Great Indian Peninsula railway, the 'Reuben Wells' had ten coupled wheels, with but 5 tons on each wheel.

The Erie railroad experiments, conducted by him in 1855, were so interesting, and so important, that he regretted to see them distorted in any way. The results comprised certain specific facts which he could not permit being even called in question. He had an engine, one of a numerous class, which, although built from the designs of a railway engineer, was nevertheless con-

structed at the works of which, in 1854, he had the mechanical charge, viz., the New Jersey Locomotive and Machine Works. He was in a position to know all its dimensions, and he carefully weighed it himself, and its weight corresponded, nearly, with that of many other engines which he had also weighed upon the Erie line. He had a train of one hundred wagons, also carefully weighed by himself. There was nothing unusual in their loading nor in their weight. Thousands of the same class of wagons, with like loads, were no doubt running now. As for the railway, 455 miles in length, it had been resurveyed in 1853 and 1854, and the levels, fifty-two to the mile, or nearly twenty-four thousand in number, were most carefully taken, and the level-books were in his own keeping for nearly two months before making his report. He had also an official section of the line still in his possession, prepared, however, from an earlier, or perhaps the original survey, yet almost identical with the later survey, as was, indeed, to have been expected. There was no doubt, therefore, as to the gradients and curves, none as to the load, none as to the size and weight of the engine. Mr. Hemans had estimated the total resistances, in one case, as something above 16,000 lbs. Had they been as much the engine could have overcome them only by maintaining a uniform cylinder pressure of 140 lbs. per square inch on the pistons throughout their whole stroke, whereas but 130 lbs. pressure was maintained in the boiler. Besides, the estimated resistance of 16,000 lbs. would have required that the adhesion should be two-fifths of the weight—40,050 lbs.—on the four coupled driving-wheels. The trials were made without the least intention of proving anything assumed beforehand, and he submitted that they had better be accepted, and studied, and worked upon, instead of being argued away, or perverted into a mathematical *reductio ad absurdum*.

He was well aware of the difficulties in the way of any experiments, upon a commercial scale, upon a large stock of railway machinery. It was more or less perilous to the railway engineer or manager who attempted to break through a great system already elaborated in a thousand details. It was not his wish, in any way, to force any feature of American practice upon the notice, still less the adoption, of the profession in this country; but he had somewhat carefully prepared a plain statement of what was really done abroad, and it would be for engineers and managers of railways to prove, as they might do, its truthfulness, and then to decide what might or might not be advantageous in the way of change.

Mr. Gregory, President, expressed the regret of the Council at being compelled to limit the discussion in order that other subjects might be taken up, because it was felt that a large measure of information might still be contributed upon it. At the same time it would be found that in the Paper and in the discussion, a

great deal of valuable information on a most important subject had been added to the records of the Institution.

Mr. J. J. Birckel observed, through the Secretary, that the discussion of this subject should be considered in connection with the construction and character of the permanent way, because the one must be, in a great measure, dependent on the other.

Attention had been called, in the course of the Paper, to the unsubstantial character of American railroads; and he could say, from personal observation, that such a statement could scarcely be exaggerated. He could not, for instance, recollect a single railway chair except at crossings; and he had often seen the rails, with the sleepers, yield 1 inch or more under the load of a passing engine. American railroads had no greater permanency than a contractor's temporary road in England.

To account for this he had been told that, as America was a new country, whose resources were as yet undeveloped, and to a great extent unknown, the railways had been made to answer the wants of the present generation; that a succeeding generation might find it necessary to remodel the railway system entirely; and consequently that a greater outlay on them would be waste of money.

Another cause of the unsubstantial character of the superstructure of American railroads was the severity of the winters, and the disintegrating force periodically at work, produced by that severe frosts and frequent thaws, accompanied usually by destructive floods, the result of the melting of heavy snows. In Canada the railroads had been constructed by English engineers, and they had found it necessary to Americanize the whole of the rolling stock. He knew for a certainty that the leading wheels of the engines sent out from England had been removed, and replaced by bogies.

It had been said of the bogie, that it had grown out of Mr. Chapman's invention of 1812; and the recommendation of its use on American railways had been attributed to the elder Stephenson. He might, however, be permitted to doubt whether any merit attached to the fact of adapting the bogie to railroad carriages, seeing that there was never so rudely constructed a four-wheel cart for common road traffic, but that had its two-wheel bogie. The use of the bogie in the rolling stock of railways seemed to him but natural, and the idea had to be borrowed only from the practice of a common country carpenter. Upon American railroads, with their loosely-laid track, the bogie was almost as absolute a necessity as it was in a common road vehicle; and as the maximum speed at which these trains travelled did not much exceed one half the speed on English railways, it answered very well. There could be little doubt, however, that the speed of American railway travelling was

a natural sequence of the construction of the permanent way and of the rolling stock; and if this were so, it might confidently be asserted, that the bogie would never form an essential feature of the rolling stock of English railways. In fact, the radiating axle box of which Mr. Adams had spoken had been tried, but the only engine which had been constructed on that system had been laid up in the sheds of the London and North Western railway at Crewe in 1864; and Mr. Ramsbottom had told him that whatever advantages it possessed for going round curves, were more than counterbalanced by the unsteadiness of its motion on a straight line; and this defect would probably arise in an aggravated degree from the use of the bogie.

The great length of the American railway cars caused them to pitch and toss so much, even at the moderate speed mentioned, that on several occasions it had nearly produced the effects of sea-sickness upon him. Sleeping-cars, however, even of the worst kind, were a great boon to those who had to travel over distances of 1,000 miles, or 2,000 miles, or more, in a single journey.

The explanation to the somewhat remarkable results of the Author's experiments on train resistances was to be sought, he believed, chiefly in the fact of the looseness of American railway construction. A train running upon rails that yielded readily on its passage, met with less resistance than if the rails were rigid; and a carriage or machine whose moving parts were loosely fitted together, offered less resistance to motion than one whose several moving parts fitted each other perfectly. He had once seen, in this country, an engine fresh from the erecting shop, which barely could start with 40 lbs. of steam-pressure in the boiler, implying a resistance of from 75 lbs. to 100 lbs. per ton of its own weight; and although this was an extreme case, it showed to what results very accurate fittings might lead. Due allowance must also be made for the element of speed, since railway resistance, considered in the aggregate, was the product of a certain factor, variable, no doubt, multiplied by the square of the velocity.

As regarded adhesion upon the rails, it was known that Count Pambour gave $\frac{1}{7}$th of the load on the driving-wheels as a safe working factor; but Mr. Birckel believed that, in his experiments in this country, he found it to vary between $\frac{1}{3}$rd and $\frac{1}{27}$th. On the other hand, General Morin gave the coefficient of friction of iron upon iron as 0·19, or nearly $\frac{1}{5}$th; and some experiments by Mr. George Rennie gave 0·14 for a pressure of $32\frac{1}{2}$ lbs. per square inch, which gradually increased to 0·4, with a pressure of 4 cwt. per square inch. An adhesion, therefore, of 0·25 did not seem very extraordinary, especially when it was remembered that the experiments were made at a time when the rails were at a high temperature.

The theory, that the coefficient of friction or adhesion increased with the temperature of metallic bodies in contact, was supported by the physical knowledge of metals, and was well illustrated by the phenomenon of 'galling,' and in the case of iron, by that of welding, and he thought it would be well to institute experiments on this subject.

Of American locomotives generally, it might be said that there was more structural uniformity among them throughout the States than there was in the United Kingdom, where every locomotive superintendent managed to graft his own peculiar notions upon the stock under his control. Here the builder had gradually become the servant of the locomotive superintendent: in the States the builder was still allowed to have his own way in the matter of constructive detail; and it followed naturally that builders varied the design of internal detail as little as possible.

Of American engine-fitting and repairing, it might be said that if it was considerably cheaper than in this country, as he believed it to be, the secret of the fact resided in the free use of the liner and the packing-piece. This was so much the case that individual parts of the machinery were made at the outset with a view to their receiving liners hereafter, in order to take up wear—a principle of construction which no engineer in England would tolerate. The other cardinal differences between American and English locomotives, to which attention had been called, might be chiefly accounted for by circumstances to which he had already alluded. Thus, with a roadway whose foundation was unsafe from natural causes, and with frosts which rendered wrought iron as brittle as cast iron, it was not likely that American engineers would study the safety of trains by adopting wrought-iron instead of cast-iron wheels; but in view of the great economy that resulted therefrom, it was a subject deserving of inquiry whether the use of cast-iron wheels—even of spoke-wheels from 5 feet to 6 feet in diameter,—had been a source of danger to trains.

Again, with a roadway which naturally led to unsteady motion, it was not likely that they would build inside cylinder engines, with a view to having engines that would run straight.

The use of wrought iron for the material of the inside fire-boxes in America instead of copper, as was invariably the case here, and generally on the Continent, might arise from a disregard of economy of fuel; but he believed there were no data on the comparative economy of locomotive boilers made with iron and with copper fire-boxes; and when it was remembered that marine boilers were now invariably made with iron flues and tubes, it became a question whether the English practice in locomotive engineering had not been rather the effect of routine than the necessary sequence of experience.

Mr. Oswald Younghusband remarked, through the Secretary, that he had seen a great deal of the American system of railways during the last few years in the countries on the shores of the Pacific, and had also travelled several thousand miles in the United States and Canada. He had found oil-boxes more economical, requiring less attention, and preferable in every respect to grease-boxes; while experiments show the great advantage they possessed in respect of friction. On the Lima railways the passenger cars usually ran from three months to four months before renewal of oil and 'waste' was required. But the goods wagons, which stood usually in unenclosed sidings, were frequently robbed of the oil in the axle boxes by the negroes, who took it to fry their fish in. Then as to head lights; the single large light used by the Americans on their locomotives was, in his opinion, much superior to the pair of lights in use in England. Instead of two, more or less uncertain, beams of light, the single large light thoroughly illuminated the space in front of it for a considerable distance. Indeed, the engineer-in-chief of an American railway once told him, that with one of these lights he could read small newspaper-print half a mile distant, on a wet night! But without giving credit to any such figures of speech, it certainly was a matter of surprise that American lights had not been tried in England, especially on such a line as the Metropolitan.

He might mention, too, an engine turntable of great simplicity. It was balanced on a pivot in the centre, and could be easily and rapidly worked by one man. This table, when unloaded, was so nicely balanced that he had, without any extraordinary exertion, and by merely a good push, made it revolve a little over three times, before it came to a stop. The cost was 1,500 dollars in gold, in the States.

The passenger cars were well suited for the traffic in the States. He had travelled in them some thousands of miles, without being inconvenienced in any way by the number, or condition of his fellow-passengers; but it must be evident that an unpleasant episode might occur at any moment. The sleeping and hotel cars deserved great praise: he found the sleeping-berth as comfortable, and more roomy than a berth in a Cunard or Royal Mail Steamer; and it certainly was a great comfort, and very refreshing, to be able to dress, wash, and have a really good breakfast, without the hurry or confusion usual at a station refreshment-room.

In speaking of American cars, it should be remembered that whereas in England a journey might last twelve hours, or even eighteen hours, in America it might last thirty-six hours, or forty-eight hours at a stretch; and the time was made much less wearisome and oppressive by the facility afforded for eating, sleeping, and moving from car to car in the train; and somewhat by the airiness,

the light, and the greater view gained by the form of the American car. For very long rides, such as from Western Europe to the Bosphorus, or in any case where many hours must be spent in the train, he thought the American car, or some modification of it, would be far preferable to the recognized English type, especially in hot climates. He had travelled from New York to Chicago, a distance of 1,080 miles, in thirty-five hours, including two lengthy stoppages of twenty-five minutes each, and calling at almost every station on the line, as was the custom with the so-called 'Express' in the States. This would give for this distance a speed of more than 30 miles per hour on the average, and he believed a speed of 50 miles per hour was often attained. This was on cast-iron chilled wheels. It was worthy of remark that the fare for this journey was advertised at 20 dollars, currency, equal to about 1 dollar, or 3 shillings, for 54 miles.

The chilled wheels were made from cold-blast charcoal iron, obtained from red hæmatite ore, derived chiefly from the Salisbury vein, situated about 70 miles from New York. They were in general use on the railways in Chili and Peru, the Panama line, the United States, and Canada; on some lines in Russia, and on the Argentine railway, and possibly elsewhere. The lines in Chili and Peru had very steep gradients, and sharp curves, and the treatment the wheels underwent was decidedly rough. On the Caldera line, the same wheels had been in use, it was stated, for fifteen years. On the Arica and Tacna, some had been running since 1855, or thirteen years; also on the Coquimbo railway—on the extension of which to Panulcillo existed the exceptional incline of Las Cardas, of 1 in 25 for 5⅓ miles, and curves of 575 feet radius, worked by locomotives. Other lines on the coast with very heavy gradients might be mentioned. On the Lima railway, cast chilled wheels had been running since 1858, and some only had been quite lately changed. He considered that some of these wheels must have run from 160,000 miles to 180,000 miles, at a moderate calculation. A set of wheels had run continuously for eight years under the break-van on this line, and at the expiration of this period were removed, and though somewhat worn, were sufficiently good to put under a goods truck for further duty. If, then, they would stand the rough treatment on lines with gradients ranging from 1 in 25 upwards, and sharp curves; the high rates of speed frequently obtained in the States; the rough roads, and extreme changes of temperature there, and in the Canadas, when, with the mercury down at times to zero, the road had become as hard as rock, and inelastic to the passing load—if under such circumstances these wheels had been, and were, preferred to wrought-iron wheels, there could be no doubt as to their durability and safety. The economy that would result from their use was the only point of practical importance remaining to

be considered. The calculations which he submitted showed results very favourable to the chilled wheel as compared, in various ways, with the wrought-iron wheel, and that a saving of importance would be attained by the adoption of the former. This would be even more striking on some foreign and colonial lines, where every item of time and labour saved in mechanics' wages, in machinery and tools, in shifting wheels, and sending wagons into shop, or in wagons lying idle during repairs, &c., amounted to at least double or treble what the same items represented in England. It was difficult to fix on a wrought-iron wheel as a standard to compare with the cast-iron wheel; it became, therefore, necessary to consider more than one class of wrought-iron wheel. Calculation No. 1 was given essentially from an American point of view, the English wheels in use running only 20,000 miles before requiring turning up; and the result justified the assertion made on the other side of the Atlantic, as to the decided economy in the use of cast-iron wheels.

The life of the chilled wheel might be safely taken at 150,000 miles. There were examples of some that had run in Canada 160,000 miles, which were still in good order. Experience in South America further corroborated this. For the sake of comparison, he took the life at 150,000 miles. The price for a wheel 36 inches in diameter, weighing about 500 lbs., F.O.B., in the States, was taken at £4. 7*s.* each, or £17. 8*s.* the set.

In the first case, he took the wrought-iron wheel at £18. 5*s.* the set with axles. Wheels of low price, but of fair average quality, by good makers, might be quoted at from £18 5*s.* to £21. 10*s.* the set; and first-class wheels for carriages and express speeds, at from £28 to £32 per set. The price of the wheel depended on the durability of the tire; and making due allowance for this, as was obvious in the following calculations, he believed he had arrived at results substantially correct. Should this prove to be so, a saving of no small importance might be effected by every railway company in England and abroad; for it amounted to about the rate of £4,000 per annum on every stock consisting of one thousand wagons. On a large railway stock, like that of the London and North Western, for instance, it would represent, on a stock of nearly thirty thousand wagons, £120,000 per annum; or, supposing the average mileage of the wagon-stock to be only 25,000 miles per annum, the saving would amount to £60,000 a year, without taking into consideration other incidental advantages.

Were the chilled wheels in demand in Europe or the colonies, they would be manufactured in England, and the price would be reduced, it was calculated, £2 or £3 the set. This would be a great step; while if, as Major Palliser stated, a method had been discovered in the course of his experiments, of giving certain mixtures

of ordinary iron ores a 'chill' and great tensile strength, there should be no delay in bringing the subject forward.

CALCULATION No. 1.

Cast-iron chilled disc wheel, at £4. 7*s.* each.

Compared with wrought-iron wheel and axles, at £18. 5*s.* the set.

	£.	*s.*	*d.*
One wrought-iron wheel, at £18. 5*s.* the set	4	11	3
*Turning up three times, at 6*s.* each time	0	18	0
New tire at end of first 75,000 miles	2	10	0
Turning up three times during second 75,000 miles, at 6*s.*	0	18	0
New tire at end of 150,000 miles	2	10	0
Total cost of one wrought-iron wheel during 150,000 miles, and placed in condition to run again	11	7	3
Total cost of one set of four wheels	£45	9	0

	£.	*s.*	*d.*			
Total cost of one set of four chilled wheels	17	8	0			
Two 6 ton axles	6	0	0			
Renewing wheels at end of 150,000 miles at one half original cost; say £2. 5*s.* each	9	0	0			
				32	8	0
Result; balance in favour of chilled cast wheel per wagon of four wheels during a life of 150,000 miles, and renewed fit to start again				£13	1	0

Say £13 per wagon.

The wheels in the States ran about 50,000 miles per annum, and were changed every three years on the average. Therefore the result would be—

	£.	£.	
Per 100 wagons	1,300, or	433	per annum.
„ 1,000 „	13,000, „	4,333	„
„ 10,000 „	130,000, „	43,333	„

CALCULATION No. 2.

Cast-iron wheel as before, at £4. 7*s.* each.

Compared with wrought-iron wheel, at £26 the set.

	£.	*s.*	*d.*
One wrought-iron wheel, at £26 the set	6	10	0
Turning up three times during 150,000 miles, at 6*s.*, assuming this wheel to run 40,000 miles before turning up	0	18	0
Add new tire at end of 150,000 miles, at 30*s.* per cwt.	3	10	0
Total cost of wrought-iron wheel, having run 150,000 miles, and ready to start afresh	£10	18	0

	£.	*s.*	*d.*
Total cost of one set of four wrought-iron wheels	£43	12	0
The set of cast-iron wheels, as in Calculation No. 1, renewed as before, and ready to start afresh	32	8	0
Result; balance in favour of chilled wheels per set, &c.	£11	4	0

Say £11 per wagon.

* This was a moderate charge for turning up abroad.

		£.	£.	
Per	100 wagons . .	1,100 or	366	per annum.
„	1,000 „ . .	11,000 „	3,666	„
„	10,000 „ . .	110,000 „	36,666	„

This result was not so satisfactory as the preceding case. But the price of the wheels was taken at £4. 7*s.* each, while the price stated in the Paper was £2. 10*s.* to £3. 10*s.* In Calculation No. 3, therefore, he took £3. 10*s.* as the price, and 2*s.* per wrought-iron wheel for the turning.

CALCULATION No. 3.

The cast-iron wheel as before taken, at £3. 10*s.* each.
Compared with wrought-iron wheel at £26 the set.

	£.	*s.*	*d.*	£.	*s.*	*d.*
One wrought-iron wheel, at £26 the set				6	10	0
Turning, as before, at 2*s* each time				0	6	0
New tire, as before				3	10	0
Total cost of one wheel, as before				£10	6	0
Total cost of one set of wrought-iron wheels, as before				£41	4	0
One chilled wheel	3	10	0			
The set of four wheels	£14	0	0			
The two axles, as before	6	0	0			
New wheels; renewed as before, at £2. 5*s.* each, ready to start again	9	0	0			
Total cost of set of four wheels, renewed as before . . .				29	0	0
Result; balance in favour of chilled wheels per set, and as before . .				£12	4	0

Say £12 per wagon.

			£.		£.	
Per	100 wagons	=	1,200	or	400	per annum.
„	1,000 „	=	12,000	„	4,000	„
„	10,000 „	=	120,000	„	40,000	„

It had been said that there were good wrought-iron wheels that would run from 70,000 miles to 80,000 miles before requiring turning up. If so, taking 75,000 miles, for such a wheel, and the price at, say, £30 per set, the calculation would then be as in No. 4.

CALCULATION No. 4.

Cast-iron wheel as before, at £3. 10*s.* each
Compared with a wheel supposed to run 75,000 miles before turning up; the tire to stand four turnings, and the price £30 the set.

	£.	*s.*	*d.*
One wrought-iron wheel, as above	7	10	0
Turning at end of first 75,000 miles, at 2*s*..	0	2	0
„ „ second 75,000 miles, and wheel ready to start afresh	0	2	0
Total cost of one wheel at end of 150,000 miles	£7	14	0

	£.	s.	d.
Total cost of the set of four at the end of 150,000 miles	30	16	0
Total cost of set of cast chilled wheels, renewed at end of 150,000 miles, and ready to start again, as in No. 3.	29	0	0
Balance in favour of set of chilled wheels	£1	16	0

at this stage of life of the wrought-iron wheel. If followed farther—to say 300,000 miles—it would require a new tire, and be ready to start afresh.

	£.	s.	d.
Wrought-iron wheel, as above	7	10	0
Turning up four times, at 2*s*.	0	8	0
New tire	3	10	0
Total cost of one wheel at end of 300,000 miles	£11	8	0
Total cost of set, ready to run again	£45	12	0
Cost of set of cast chilled wheels, after running 150,000 miles: and renewed to start again 29 0 0			
Renewed at end of 300,000 miles 9 0 0			
	38	0	0
Balance in favour of chilled wheels	£7	12	0

This case was pure assumption, so far as regarded the wrought-iron wheel. Its first cost would also be against it, viz., £30 per set, as against £20, or perhaps £18, the utmost price being taken for the cast-iron wheel, and its life limited to 150,000 miles.

March 16, 23, and April 6, 1869.

CHARLES HUTTON GREGORY, President, in the Chair.

The Discussion upon the Paper No. 1,230, "On American Locomotives and Rolling Stock," by Mr. Colburn, was continued throughout these evenings, to the exclusion of any other subject.

At the Meeting of March 23rd. His Majesty Napoleon III., Emperor of the French, was elected by acclamation an Honorary Member.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously—

> "That, in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 6th of April."

At the Meeting of April 6th, the following Candidates were balloted for and duly elected:—William Adams, as a Member; William Francis Badgley, Arthur Carpmael, William Hackney, B. Sc., Francis Henry Hambleton, Thomas Crump Hambling, Charles Benjamin Knorpp, William Francis Lawrence, Richard Arthur Sargeaunt, Lieut. R.E., and George Frederic Verdon, C.B., as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Section IV. of the Bye Laws, as Students of the Institution: Henry Carter, William Alfred Dawson, and John Henry Richard King.

April 13, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,222.—"Experiments on the Standards of Comparison employed for testing the Illuminating Power of Coal Gas."[1] By Thomas Nesham Kirkham, M. Inst. C.E.

The standards of comparison at present in use are known to all those who have been in the habit of testing the illuminating power of gas, to be wanting in that uniformity of result necessary for determining with accuracy the difference in the intensities of two lights; but the amount of the variation has never up to this time been clearly defined.

Before describing the series of experiments undertaken by the Author, with a view of ascertaining the extent of these differences, it may be advisable to explain, briefly, the principles upon which the several appliances now in use, for ascertaining the difference in intensity of two lights, are constructed, and what the standards of comparison really are.

The application of the law of optics, that light diverging in any direction from a luminous centre diminishes in intensity in the ratio of the square of the distance, affords a ready means of determining the relative illuminating qualities of two flames. Thus, let a screen of white paper be placed vertically at a given distance from a lighted candle, and a piece of wire be fixed between them near to the paper, so that the shadow from the wire may be cast upon it; and let some other light be placed in such a position that it may project another shadow from the wire on to the paper, in close proximity with that already there; then, if the intensity of the two shadows differs, move one of the lights till the shadows become equal. When this has been done, measure the respective distances of the flames from the screen, square them, and the results obtained will represent the relative intensities of the two lights. Upon this principle Count Rumford constructed the instrument known as the Shadow Photometer.

Another method, suggested by Professor Bunsen, depends for its action upon the combination of reflected and transmitted light. As an illustration of the application of this system, take a piece of white paper, and saturate it with spermaceti, leaving a spot, $1\frac{1}{2}$ inch

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

in diameter, in the centre of the paper untouched. If a lighted candle be placed opposite one side of the paper, the spot in the centre on that side will appear white, the light falling upon it being reflected back to the eyes of the observer. On removing the candle to the other side of the paper, without any change of position on the part of the observer, the spot will appear dark, in consequence of being viewed by transmitted light, which passes through that part of the paper rendered transparent by the spermaceti.

On fixing two lights at a certain distance from each other and interposing the prepared paper, it will be seen that in moving it in a horizontal direction between the lights, this difference will disappear, and the paper will present one uniform shade on each side, directly it reaches the point where the two lights are equal.

These, then, are the principles adopted in the construction of the instruments at present employed for ascertaining the comparative illuminating power of two flames; and, without entering into a detailed explanation of the numerous ingenious arrangements that have been suggested for carrying these principles into effect, it will be sufficient to give a description of the apparatus and standards of comparison sanctioned by the Municipality of Paris, and by Act of Parliament in England.

In France, the instrument employed is M. Foucault's modification of that proposed by Count Rumford, as arranged by MM. Dumas and Regnault. The standard of comparison is the amount of light emitted from 10 grammes of Colza oil, specially prepared and verified, burning in a Carcel lamp of certain fixed proportions, at the rate of 42 grammes (648 grains) per hour; and it is required that the light produced by from 25 litres to $27\frac{1}{2}$ litres (0·8625 to 0·9707 of a cubic foot) of gas, consumed in an Argand (Bengel) burner, also of certain fixed proportions, and having thirty holes, shall be of equal power.

Plate 18, Figs. 1, 2, and 3, are illustrations of this instrument. Fig. 1 is the front elevation, with a portion removed, so as to expose the lamp *l*, and the gas-burner *g*. Fig. 2 is a longitudinal section; and Fig. 3, a sectional plan, in which *l* is the lamp and balance, *b* the bell for warning the operator, *g* the gas-burner, *m* the meter for registering the quantity of gas consumed, *r* the cock for regulating the quantity of gas supplied to the burner *g*, *x* the lever for putting in motion and stopping the hand of the meter and the seconds' clock, and *d* the disc or lunette, placed equidistant from the lamp and the gas-burner. This disc is simply a circular piece of glass rendered opalescent, and divided by means of a brass partition into two semicircles, one of which is illuminated by the lamp, and the other by the gas. The mode of conducting an experiment with this instrument is as follows:—The gas, at the burner *g*, is lighted, and allowed to burn for some time.

The lamp is trimmed, lighted, and regulated to its normal consumption. At the commencement of the experiment, the lamp is placed in the balance and counterpoised, care being taken to put a supplementary weight in the pan attached to the lamp side of the balance. The light of the gas is now regulated by the cock *r*, so as to equal that of the lamp, and the reading of the meter at the stationary hand is taken. When the balance comes into equilibrium, a hammer falls and strikes a bell attached to the side of the balance; or, as shown in the Figs., an electric contact is produced by the pointer which causes the bell to ring,—thus warning the operator (who has stationed himself in front of the apparatus) to put in motion by a single movement of the lever, both the hand of the meter and the seconds' clock. A weight of 10 grammes (154·38 grains), representing the normal quantity of oil that will be consumed in fourteen minutes seventeen seconds, is now placed on the lamp side of the balance, and the instant that quantity of oil has been consumed, the bell again gives warning, when the operator stops, by means of the lever, both the hand of the meter and the seconds' clock. During the time the oil is being consumed, the operator must watch the lunette, and so regulate the quantity of gas, by means of the cock *r*, that the two lights shall be maintained of equal intensity. In this way all the elements are obtained to enable a comparison to be made of the consumption of oil with that of the gas; and if the lamp has burned at the specified rate of 42 grammes (648 grains) per hour, the experiment should have been completed in fourteen minutes seventeen seconds.

In England, the instrument in use is constructed on the Bunsen principle, and the standard of comparison, as defined by Act of Parliament, is a sperm candle, burning at the rate of 120 grains (7·77 grammes) per hour; the gas being consumed at the rate of 5 cubic feet per hour, through an Argand burner having fifteen holes, and with a chimney 7 inches high, must be equal in intensity of light to twelve such candles.[1]

The instrument by means of which the following experiments were made was also constructed on the Bunsen principle, combining all the most approved modifications. It consists of four Photometers, radiating from one common centre, in the form of a 'Cross,' and each accurately scaled, adjusted, and fitted with every appliance to insure uniformity and precision. The 'Cross' Photometer is illustrated in Plate 18, Figs. 4, 5, and 6. Fig. 4 is a sectional plan; Fig. 5, a sectional elevation on the line Z Z; and Fig. 6, the elevation, with the end of C B (candle-box) No. 1, removed, and the doors of L B (lamp-box), Nos. 1 and 2, open, exposing the

[1] As, however, twelve sperm candles are not used in experiments, but only one, or at most two, it results that the two lights compared together in the French test are more equal in power than in the English test.

lamps and balances, which were fitted to the photometer for the purpose to be afterwards explained, provision being made for the substitution of candles when required. Fig. 4 shows the position of the gas under comparison in the centre of the 'Cross;' and also that of the lamps and candles, as in some of the experiments lamps were substituted for candles at the photometers L B (lamp-box), Nos. 1 and 2. For the purpose of regulating and measuring the quantity of gas consumed, and also for indicating the pressure at the burner in the centre, the apparatus is fitted with a meter, governor and delicate pressure gauge.

First Series.

The first series of experiments was undertaken with a view of arriving, if possible, at the amount of variation in the illuminating power of candles obtained from the principal manufacturers. Gas was adopted as a standard of comparison; and to insure uniformity in its illuminating power, a sufficient quantity for carrying out the experiments, on each occasion, was put into a gas-holder in the laboratory, the temperature in the latter being always maintained at 62° Fahrenheit. A suitable Argand burner was used, burning an unvarying quantity of 5 cubic feet per hour. In this series, each of the four photometers was supplied with candles of a particular make, to the use of which it was restricted throughout the day, every successive experiment being made with a separate specimen. All the candles were cut in half, and burned from the centre. Attention is particularly directed to the fact, that although the standard candle is fixed by Act of Parliament, as a sperm candle of six to the pound, burning uniformly at the rate of 120 grains per hour, yet no such candle is to be obtained; for from various quantities of sperm candles, six to the pound, procured from several manufacturers, the average rate of consumption is 135 grains. This is clearly demonstrated in the extended series of experiments, carried out by Professors Brande and Graham, Dr. Leeson, and Mr. J. T. Cooper, in 1852;[1] and is verified by those made by the Author, and now presented to the Institution.

The Parliamentary rate, being abnormal, is so rarely met with, that all operators have been compelled to make corrections for these variations, and have unanimously adopted the ordinary rule of simple proportion for that purpose. It is proposed, therefore, in the analysis of the diagrams[2] (Plate 19), exhibiting the results of the experiments, that the candles burning at the rate of 135 grains should

[1] *Vide* "The Great Central Gas Consumers' Company.—Report of the Proceedings on the Arbitration between A. A. Croll, Esq., and the Great Central Gas Company." 8vo. London. No date. [Reprinted from the "Journal of Gas Lighting," &c.] Page 223 *et seq.*

[2] In these diagrams the vertical lines show the number of grains of sperm consumed, and the horizontal lines the number of candles the standard gas represents.

be designated 'normal standard candles,' to distinguish them from the Parliamentary standard of 120 grains. Each operator, at the conclusion of every experiment, stamped the sign of his photometer upon the diagram at the point where the vertical line, representing the consumption of sperm, intersected the horizontal line, representing the illuminating power as read off the photometer scale; the readings were then corrected by simple proportion, and the result stamped also upon the diagram.

Diagrams 1 and 1a, Plate 19. Commencing with experiments Nos. 56 and 58, in No. 56, with a consumption of 119 grains, the illuminating power of the standard gas is represented as 15·3 candles; whilst in No. 58, with a consumption of 121·2 grains, it is 14·5 candles. The difference between these two experiments, made with candles which happen to be nearly within the Parliamentary standard, is ·8 of a candle. In experiment No. 51, burning the normal standard quantity of 135 grains, the same gas is represented as being 15·48 candles; and in No. 61, consuming 134·4 grains, or ·6 of a grain less, it is shown to be 16·28 candles, the difference being in this case also, ·8 of a candle. In experiment No. 60, with a consumption of 134·7 grains, or only ·3 of a grain more, the gas was shown to be equal to 18·18 candles, a difference of 2·70 candles. Thus candles, practically burning the same amount of sperm per hour, show a difference in the illuminating power of the gas of 2·70 candles. In experiment No. 51, with a consumption of 129 grains of sperm, the gas is shown, by the reading of the photometer, to have an illuminating power of 12·6 candles. In experiment No. 52, with a consumption of 145·2 grains, the gas appears, from the reading of the photometer, also to be equal to 12·6 candles. Experiment No. 52, with a consumption of 157·2 grains, shows the gas to be equal to 12·54 candles, by the reading of the photometer. The last three experiments were examples of candles consuming different quantities of sperm, yet giving the same amount of light; the correction of which to the Parliamentary standard of 120 grains creates error. Experiments Nos. 57 and 54, each with the same consumption of 130·2 grains, show the difference in the illuminating power of the gas to be 2·42 candles; the former representing it as 13·02, and the latter as 15·44 candles, by the readings of the photometer. These are examples of candles burning the same quantity of sperm, yet giving a different amount of light. The greatest difference in the illuminating power of the 'standard gas,' shown throughout the forty-four experiments made upon this day, was 4·60 candles; being between experiment No. 51, with a consumption of 129 grains, giving an illuminating power of 13·58 candles, and experiment No. 60, consuming 134·7 grains, representing the gas to be 18·18 candles.

An examination of the various diagrams demonstrates, that the

differences in the candles may be classed under five heads, viz.: First. Differences in the illuminating power of Parliamentary standard candles, burning at the rate of 120 grains per hour. Secondly. Differences in the illuminating power of normal standard candles, burning at the rate of 135 grains per hour. Thirdly. Candles with different rates of consumption, giving the same amount of light. Fourthly. Candles with the same rates of consumption, giving a different amount of light. And fifthly. Greatest differences of illuminating power, in the whole number of experiments, when corrected to the Parliamentary standard.

From the following tabulated results of three other sets of experiments belonging to this series, it appears that in one, (Diagram No. 4,) where the consumption of sperm varies from 109·2 grains to 134·4 grains, the greatest difference in the illuminating power of the gas, corrected to the Parliamentary standard, is 4·59 candles. In the next, (Diagram No. 5,) where the consumption ranges from 120·9 grains to 130·8 grains, this difference is 3·06 candles; while in the third, (Diagram No. 6,) with a consumption of from 120 grains to 142·5 grains, the difference is 4·21 candles.

Diagrams Nos. 4 and 4a, Plate 19.

	Nos. of Experiments.	Consumption of Sperm by the Candles in grains per hour.	Difference in Illuminating Power, corrected to the Parliamentary Standard, in No. of Candles.
Difference in Illuminating Power of Parliamentary Standard Candles of 120 grains per hour	.. ..	.. ..	..
Difference in Illuminating Power of Normal Standard Candles of 135 grains per hour	81 & 80	134·1 & 134·4	2·28
Candles giving same amount of Light, but consuming different quantities of material	83 & 85	109·2 & 140·1	3·53
Candles consuming same quantity of material, but giving different amounts of Light	81 & 80	134·1 & 134·4	2·28
Greatest difference in Illuminating Power of Gas, corrected to the Parliamentary Standard, shown in the whole number of Experiments	83 & 80	109·2 & 134·4	4·59

Diagrams Nos. 5 and 5a, Plate 19.

	Nos. of Experiments.	Consumption of Sperm by the Candles in grains per hour.	Difference in Illuminating Power, corrected to the Parliamentary Standard, in No. of Candles.
Difference in Illuminating Power of Parliamentary Standard Candles of 120 grains per hour	.. ..	.. ..	..
Difference in Illuminating Power of Normal Standard Candles of 135 grains per hour	.. ..	.. ..	..
Candles giving same amount of Light, but consuming different quantities of material	1 & 5	120·9 & 144	2·57
Candles consuming same quantity of material, but giving different amounts of Light	2 & 4	136·2 & 136·2	·63
Greatest difference in Illuminating Power of Gas, corrected to the Parliamentary Standard, shown in the whole number of Experiments	1 & 5	120·9 & 130·8	3·06

Diagrams Nos. 6 and 6a, Plate 19.

Difference in Illuminating Power of Parliamentary Standard Candles of 120 grains per hour	6 & 6	120· & 120·3	·43
Difference in Illuminating Power of Normal Standard Candles of 135 grains per hour	.. ..	.. ..	..
Candles giving same amount of Light, but consuming different quantities of material	6 & 9	120· & 146·1	2·83
Candles consuming same quantity of material, but giving different amounts of Light	8 & 7	142·5 & 142·5	2·30
Greatest difference in Illuminating Power of Gas, corrected to the Parliamentary Standard, shown in the whole number of Experiments	6 & 7	120· & 142·5	4·21

Second Series.

The results of the first series of experiments having proved that great variations exist with regard to the amount of light eliminated from candles procured from various makers, it was resolved to institute a second series, with candles obtained from one manufacturer only. Although it will be seen from the diagrams, that great differences existed in these candles, yet, all points considered, they

appeared the best of the various specimens obtained, and were therefore selected for the whole of this as well as for the third and fourth series of experiments. The following Table illustrates the variations in the second series, from which it will be seen, that with a consumption of sperm varying from 129·6 grains to 130·2 grains, the greatest difference in the illuminating power is 2·26 candles.

Diagrams Nos. 7 and 7a, Plate 19.

	Nos. of Experiments.	Consumption of Sperm by the Candles in grains per hour.	Difference in Illuminating Power, corrected to the Parliamentary Standard, in No. of Candles.
Difference in Illuminating Power of Parliamentary Standard Candles of 120 grains per hour	.. ..	.. ..	..
Difference in Illuminating Power of Normal Standard Candles of 135 grains per hour	.. ..	.. ..	..
Candles giving same amount of Light, but consuming different quantities of material	16 & 15	129·6 & 134·4	0·39
Candles consuming same quantity of material, but giving different amounts of Light	16 & 16	129·6 & 129·6	0·43
Greatest difference in Illuminating Power of Gas, corrected to the Parliamentary Standard, shown in the whole number of Experiments	16 & 17	129·6 & 130·2	2·26

Third Series.

The third series of experiments was made for the purpose of ascertaining whether the French standard of comparison, when used at a photometer on the Bunsen principle, is more reliable than the candle. To carry out these experiments, two lamps, with cottons, glasses, &c., all of the dimensions sanctioned and prescribed by the Municipality of Paris, were procured, together with oil verified by the proper authorities. These lamps were put in operation at two of the photometers, the other two being supplied with candles. The time generally allowed in England for taking observations being ten minutes, it was deemed necessary to approximate the lamp experiment to the same time. Accordingly 108 grains should have been consumed in ten minutes, in order that the lamps might give an equal amount of light with that of the Paris standard. As this consumption could not be

accurately maintained, it was necessary to correct the variations. The method adopted for correcting the candle experiment, by simple proportion, was considered liable to create greater error if made use of with respect to the lamp; consequently, experiments were made to ascertain the actual increase of light, per grain of oil consumed, within certain limits. With this view, Diagram No. 10 was prepared, in which the base line represents three minutes of time, subdivided into seconds by the vertical lines, and the horizontal lines the scale of the photometer. The lamp having been lighted, and properly balanced at the end of its photometer, a weight of 108 grains was added to the lamp side of the balance, and when the quantity of oil represented by this weight was consumed, it again came into equilibrium, and gave notice by ringing the bell. The average reading of each photometer was then marked on the horizontal line (Diagram No. 10) at its intersection with the vertical line corresponding to the time required by each lamp to consume the 108 grains, and from these observations the curve was obtained, and was used for the purpose of correcting the whole of the experiments.

Diagram No. 10, Plate 19.

	Nos. of Experiments.	Time required for the consumption of 108 grains of Oil by the Lamps.	Difference in Illuminating Power, corrected by means of curve to the Standard consumption of 108 grains in 10 minutes.
Difference in Illuminating Power of Standard Lamps, consuming at the rate of 108 grains in 10 minutes. .	43 & 45	10′ 3½″ & 10′ 3″	0·50
Lamps giving same amount of Light, but consuming the oil at different rates	46 & 44	9′ 48″ & 10′ 5″	1·10
Lamps consuming the oil at the same rate, but giving different amounts of Light	50 & 49	9′ 30″ & 9′ 32″	1·60
Greatest difference in Illuminating Power of Gas, corrected to the Standard consumption of 108 grains in 10 minutes, shown in the whole number of Experiments	49 & 43	9′ 39″ & 10′ 3½″	2·30

It will be seen that, taking the whole of the lamp diagrams up to No. 10, when the lamps were allowed to burn without any

regular system of trimming, the variations are about as great as those of the candles; but in Diagram No. 10, when the lamp was trimmed before the commencement of each experiment, the variation is about the same as with the best candles. It is probable, that the results would have been much better, if the time allowed for taking each observation had been fifteen minutes instead of ten minutes. The reason for this will be obvious, when it is stated that the lamp, when filled, weighs 10 lbs, and the balances employed would not turn to less than a grain. Subsequent experiments were made with a view of ascertaining the truth of this supposition. Of this series Diagrams Nos. 10 and 10B show in one case a difference in the illuminating power of the gas corrected to the Parliamentary standard, of 1·69 candle, with a consumption of sperm ranging between 136·5 grains and 124·5 grains; while, in the other case, the greatest difference in the illuminating power of the gas, corrected to the standard consumption of 108 grains of oil in ten minutes, was 2·3 candles, when the time required for the consumption of 108 grains of oil by the lamps was respectively 9 minutes 39 seconds and 10 minutes $3\frac{1}{2}$ seconds.

Diagram No. 10B, Plate 19.

	Nos. of Experiments.	Consumption of Sperm by the Candles in grains per hour.	Difference in Illuminating Power, corrected to the Parliamentary Standard, in No. of Candles.
Difference in Illuminating Power of Parliamentary Standard Candles of 120 grains per hour	.. ..	.. ..	..
Difference in Illuminating Power of Normal Standard Candles of 135 grains per hour	.. ..	.. ..	..
Candles giving same amount of Light, but consuming different quantities of material	50 & 48	126·6 & 131·4	0·56
Candles consuming same quantity of material, but giving different amounts of Light	44 & 47	126· & 126·	1·13
Greatest difference in Illuminating Power of Gas, corrected to the Parliamentary Standard, shown in the whole number of Experiments . .	44 & 49	136·5 & 124·5	1·69

Fourth Series.

For several years past, the Author has had in operation an instrument, introduced by the late Mr. George Lowe, M. Inst. C.E.,

generally known as Lowe's Jet Photometer, for the purpose of indicating the illuminating power of the gas as it is being manufactured. Its apparent accuracy seemed to promise a more reliable means of determining the illuminating power of gas, or at least a valuable auxiliary to any other standard. Two of these jets were fixed in the laboratory, and were supplied with the same standard gas as was used in all the previous experiments. Careful observations fully bore out the preconceived opinions that had been entertained respecting this photometer; for, so long as the gas remained at the same standard, the indications of the Jet Photometer were unaltered. It was then decided to carry out a fourth series of experiments, with a view to discover the relation between the indications of this instrument and those of the French and the English standards. At the 'Cross' photometer three consecutive experiments were made upon the quality of the gas, compared with four candles burning at the same time. The results of these twelve experiments were next averaged, and accepted as the illuminating power of the gas in each case, and were marked on the Diagram No. 38. Another operator was at the same time engaged in ascertaining the quality of the gas by the French system, at the Dumas and Regnault photometer, which was properly fitted with all necessary requirements: the average of three experiments was also taken, as representing the illuminating power of the gas, and the results were likewise marked on the diagram.

Two of Mr. Lowe's Jet Photometers, fitted precisely alike, were in operation throughout these experiments; the orifice in each jet being of the same size, so that at any given pressure the height of the flame from each would be the same. The pressure at the point of ignition was regulated so as to give a flame exactly 7 inches in height, and that pressure was duly recorded. The height of the flame at a pressure of ·6 of an inch was also observed, as well as the time required for the issue of ·1 of a cubic foot of gas under each of these pressures.

Diagram No. 38 shows the results of simultaneous experiments for ascertaining the illuminating power of gases of different qualities, by two different systems, as at present existing, and by the proposed plan of testing by the jet. In explanation of that portion of the diagram entitled the 'Retrograde scale,' it will be observed that the base line is divided into a range of ·3 of an inch, and is subdivided by the vertical lines into hundredths of an inch, showing the pressure at the point of ignition of the jet photometer; the horizontal lines, indicating the illuminating power of the gas, as determined by the English system. The diagonal line A A on this diagram, illustrates the theory of ascertaining the illuminating power of gas, by means of the jet photometer, worked on the 'Retrograde system,' which may be thus stated:—"Maintaining a

7-inch flame, from an orifice of certain fixed dimensions, the illuminating power of the gas is in direct proportion, inversely, as the pressure."

Now, referring to the experiments with the French and the 'Cross' photometers, it will be remembered, that, at the conclusion of each experiment, marks were put upon the diagram, at the intersection of the vertical and the horizontal lines, respectively representing the pressure at the point of ignition of the jet, required to give a 7-inch flame, and the illuminating power of the gas. As an example, at the intersection of the lines ·45 pressure, and 20·4 candles illuminating power, will be found a mark, which indicates the value of the gas, as ascertained at the 'Cross' photometer.

The diagonal line A A being considered as the 'standard 7-inch flame,' according to the theory just advanced, gas of such an illuminating power would require a pressure of ·45 of an inch to give that 7-inch flame. It will be observed that the average result of twelve experiments very nearly coincides with the theory. On the line indicating a pressure of ·51 of an inch and 18·4 candles illuminating power, will be found another example equally coincident. Following the diagonal, towards the base line, other instances are found, at pressures of ·63, ·64, and ·68 of an inch, which tend to prove the theory. It will be seen that the highest and the lowest candle experiments are completely cut by the line.

On this diagram there is another mark, which indicates the number of litres of gas which would be required to equal 10 grammes (154·38 grains) of oil, according to the French system. The mark is placed on that line which corresponds to the pressure required to give a 7-inch flame of such gas. It will be observed by following the line A A, that the lamp experiments generally tend also to prove the theory. It is necessary to state, that the highest and the lowest lamp experiments were placed upon those of the highest and lowest candles, in order to form the corresponding scale; and their position is verified by the remainder of the lamp experiments.

Another diagram represents the 'Duration Test corresponding with the Retrograde scale.' It shows the time required for the issue of ·1 of a cubic foot of gas, of a certain illuminating power, maintaining a 7-inch flame, from the jet photometer. The use of the Duration Test is to check the working of the jet photometer, and to afford a means of discovering any irregularities that may occur in the apparatus. The base line is a facsimile of that of the 'Retrograde scale,' the vertical lines being hundredths of an inch pressure, and the horizontal lines, seconds of time. Its relative scale of illuminating power is on the left. On this diagram there are marks, each of which represents the average result of three experiments, taken simultaneously with those marked on the

retrograde scale, and are placed at the intersection of the lines representing, respectively, the time of issue of ·1 of a cubic foot of gas, and the pressure at which it issued from the jet photometer. From these experiments the curve B B was determined. As an example of the use of the Duration Test, it is seen by the retrograde scale, that gas having an illuminating power of fourteen candles, gives a 7-inch flame, at a pressure of ·63 of an inch; and upon referring to the 'Duration Test,' it will be found that ·1 of a cubic foot of gas, of that illuminating power, ought to maintain that flame for three minutes. Should there be any considerable deviation, it is an evidence of some derangement in the apparatus.

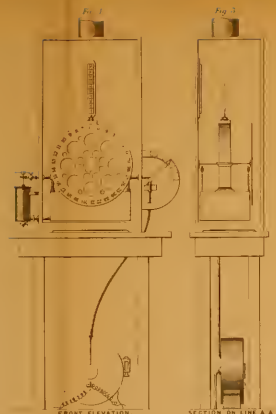
From these experiments, the Author believes it is evident that a more reliable method than that at present in use for determining the correct illuminating power of the gas supplied to the public is urgently needed; and it is thought the following system will be found to give results approaching as nearly as practicable to a truthful estimate.

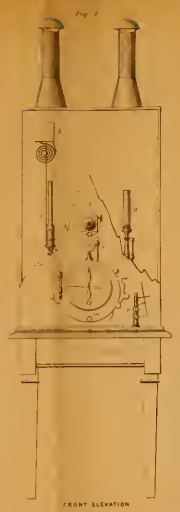
Let the illuminating power of the gas be determined by the aid of the present recognized photometer, fitted with a Carcel lamp, burning oil of the same quality, and verified in the same manner, as that adopted by the Municipality of Paris as a standard; and let a sufficient number of experiments be made, so as to cover the errors that are known to exist, and let the average of these be compared with the illuminating power, as shown by the Jet Photometer and the Duration Test, and then the 'Mean of Comparison' may be taken as the Illuminating Power of the Gas.

The communication is accompanied by a great number of Tables and Diagrams, referring to each experiment in all the four series. It is further illustrated by some of the Tables and Diagrams being drawn to a large scale, and these are reproduced in the Paper and in Plates 18 and 19.

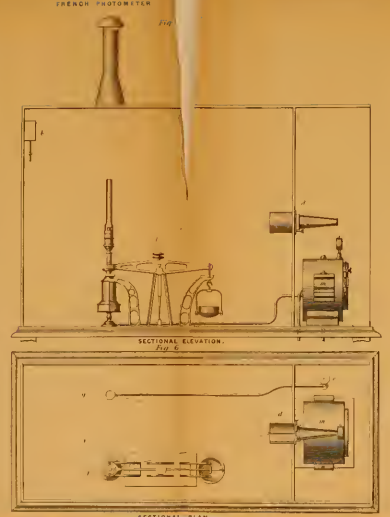
ILLUMINATING POWER OF COAL GAS.

JET PHOTOMETER

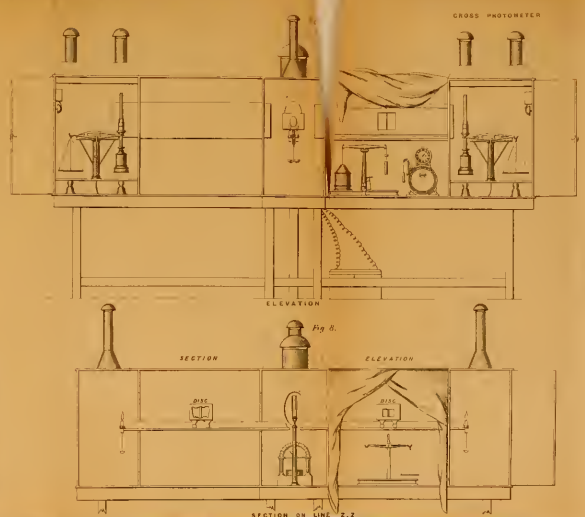


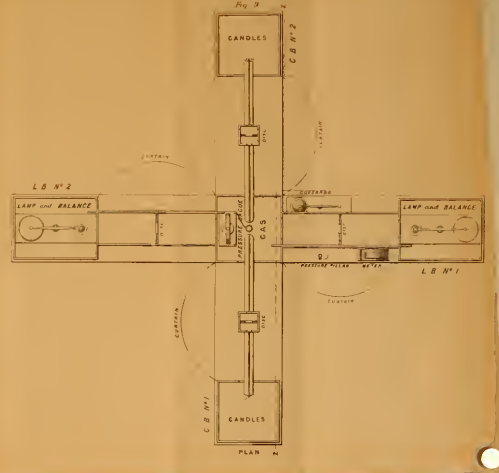


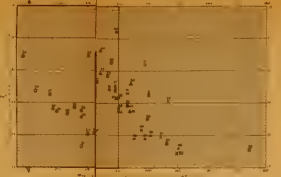
FRENCH PHOTOMETER

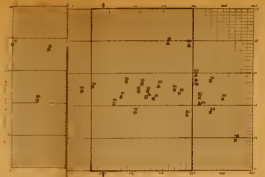


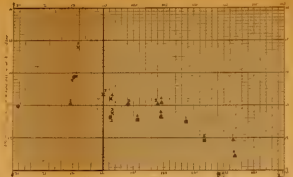
GROSS PHOTOMETER

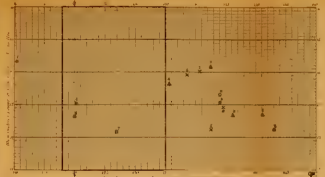


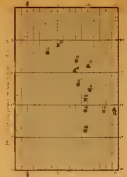


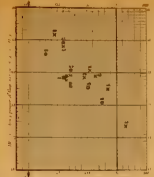


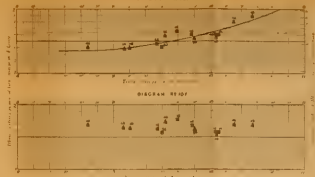


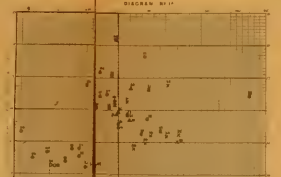


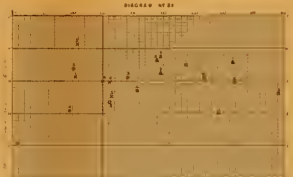


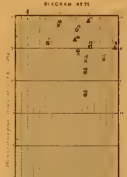


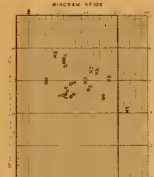


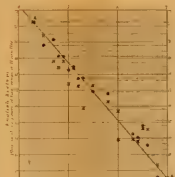




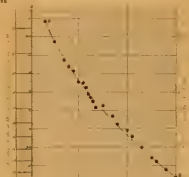








RETROGRADE SCALE



DURATION TEST

Mr. KIRKHAM said, the experiments now brought forward related only to one branch of the subject, but the series was complete, so far as regarded the standard of illumination recognised by Parliament. That standard had been arrived at from imperfect information, and on the assumption that sperm candles, six to the pound, would burn uniformly, at the rate of 120 grains per hour. The experiments proved that this was very far from being the case, and further, that if consumed regularly at that rate, such candles varied in illuminating power, as much as when there was a difference of consumption of from 123 grains to 134 grains.

He was at present carrying out a series of experiments with regard to gas-burners, which was an important part of the general inquiry. He exhibited some burners which, with the consumption of 5 cubic feet per hour, gave an illuminating power equal to sixteen candles, being as high an illuminating power as from another burner consuming nearly 14 cubic feet per hour. He did not think the construction of the burner had hitherto been sufficiently attended to, or been thoroughly investigated. From experiments he had recently made, a burner was found to give the best illuminating effect when the pressure at the point of issue, or combustion, was almost *nil*. Mr. Sugg had succeeded in producing a burner which would burn the gas with a pressure of $\frac{1}{100}$th of an inch, and that burner gave an illuminating power of about two candles above the standard burner adopted by Parliament. It might be said that that burner ought not to be used, because by so raising the illuminating power, the Act of Parliament might be evaded. This was not, however, his opinion; for a burner that was advantageous for the gas companies must also be beneficial for the consumers; in fact, better for the consumers than for the companies in many ways. With a burner which required great pressure—say $1\frac{1}{2}$ inch—and many would not burn under that—the illuminating power was greatly reduced, because too much oxygen was supplied to the gas, which was thus robbed of its illuminating power. One complaint on the part of the public was, that there was not sufficient pressure. If the pressure were raised to accommodate certain descriptions of burners, the consumer would find, in the first place, a diminution of light, and in the next he would have to pay for the increased leakage which would ensue over the whole district. From experiments he had tried with burners consuming 5 cubic feet per hour, he had found that the lower the pressure the better it was for the consumer, and for the gas maker. At present all the faults of the standards fell upon the gas maker. For instance, he made gas, and distributed it, of a certain illuminating power, which was accurately determined by photometrical measurement. The next day, according to a test taken outside the works by the tester, with a candle rather below the standard, it might

be inferred that the public got inferior gas, and that the gas was not what it should be. In this case the error was due to the standard employed, either by the tester or by the gas maker, but the gas company was blamed.

Mr. Sugg remarked that the principle on which the burner, alluded to by Mr. Kirkham, had been constructed, was this: the apertures at the top of the chamber, from which the gas issued to be consumed, were of such a size that the gas passing from the tube into this chamber should be able to issue at a much greater rate than it could come in; so that the pressure was reduced to *nil* when the burner was first lighted, but after it had been lighted a short time the heat caused the gas to expand, and it then issued from the burner at a pressure of less than $\frac{1}{100}$th of an inch. For regulating the gas, as far as the consumer was concerned—in order to bring these burners under the same conditions as those generally adopted—viz., to the pressure of $\frac{7}{10}$ths or $\frac{8}{10}$ths at the base of the burner—he had arranged a screwed cylinder, and at the top of the cylinder, on the inside of what might be called the lining of the burner, there was an inverted cone. The adjustment was made by putting a number of thin paper washers on the shoulder of the cylinder, and screwing down the burner till the aperture left by the cone was sufficiently large to allow the quantity of gas to pass up the tube into the burner. By means of a double governor at the meter the consumer could exactly regulate the quantity of gas throughout every part of the house, and once set it remained unchanged during the whole evening, even if there was any variation of pressure in the district. At present that was not the case. A variety of contrivances had been adopted, to cure the defect caused by the change of pressure necessary at the company's works, so as to give a proper amount of gas to supply the requirements of the district. At various times during the evening it was necessary to increase the pressure at the works; the consequence was, that if burners were adjusted early in the evening, and were then left, on the pressure being increased there would be an increase in the consumption of gas; and if the burners were of such a form as to suit the illuminating power with a low pressure, it was impossible that they could properly consume the extra amount of gas which was emitted when the pressure was increased. Great waste then ensued; but by the use of regulators at the meter, to insure the gas passing into the house at one uniform pressure, it was possible by these new arrangements to control every burner, so that the proper amount of light was obtained without alteration of the burner.

The bearing of the question of the burner upon the test for illuminating power was considerable: because the Act of Parliament simply defined that the burner for testing gas should be a

burner having fifteen holes. It specified neither the size of the holes, nor that of the burner: so that it was possible to take a burner which gave, by the best method of testing, gas equal to fourteen candles; and then another burner, complying with the Act, which would show that same gas to be one or perhaps two candles less. It therefore became necessary, in order to obtain something like uniformity, that a standard burner should be provided. He had made burners which were as nearly as possible uniform, and would give throughout all the districts of England, generally the same results; but the candles, which were the standard of comparison, varied in every part of London and England, to such an extent that it was impossible for anything like uniformity to be obtained. by those whose duty it was to test the gas on behalf of the public; and were it not for a kind of tacit understanding amongst themselves, the illuminating power of gas in London and throughout England could not be ascertained with any degree of certainty. If every official tester were left to proceed according to Act of Parliament, and to carry out the test in his own way, there would be nothing like uniformity, and the test would be very wide of the truth. But official testers had recognized that the Act of Parliament was deficient in its specification of how the experiments were to be performed, and had adopted another form, which was general throughout the country, but there was no authority for it in any Act of Parliament relating to gas. It was only this rule which had enabled the illuminating power of gas to be determined with accuracy. It was to be hoped that the present discussion would lead either to the proposal of some other standard, or to the adoption of some system which would give better results than those hitherto attained.

In reply to inquiries, Mr. Sugg stated that, according to the Act of Parliament, the standard burner was required to have fifteen holes, and the chimney was to be 7 inches in height. It was evident that, with a fixed number of holes, if the gas differed in illuminating power, without great care was taken as to the dimensions of the burner, a poor gas might get too much air and a richer gas too little. By altering the sizes of the apertures and orifices which admitted the air, the right quantity of air might be supplied for each particular quality of gas: therefore, if it was necessary to have burners with fifteen holes the dimensions must be varied to suit the different qualities of gas. With gas having an illuminating power of eighteen candles it was difficult to test by a 15-hole burner; indeed, such gas would, when consumed in a burner of that description, not appear, according to the photometer, to have a higher illuminating power than sixteen candles, because the holes were so wide apart that the amount of air admitted to the burner was too great, and the illuminating power was thereby destroyed.

Similar effects were produced in London from the badness of the burners. Supposing the power was increased from fourteen candles to sixteen candles without notice, the public would be dissatisfied: because the burners, not being of a proper description to consume the better quality of gas, would either smoke or destroy the illuminating power: and the probability was that, throughout London, there would be less illuminating power with an increase of two candles than if the gas was kept as it was.

Mr. Bramwell said it had been stated that, in order to get the best effect out of gas, the pressure should scarcely exceed that of the atmosphere, in fact, be as low as $\frac{1}{100}$th of an inch; and an Argand burner had been recommended by Mr. Kirkham and Mr. Sugg. Now he wished to know whether that was regarded as the proper burner merely for ascertaining the illuminating power of gas, or whether it was the best for ordinary use, in preference to the batswing. If so he would ask whether it was possible to use burners of that description with a pressure of $\frac{1}{100}$th of an inch, especially in an ordinary sitting-room, where there was a fire, as the mere opening or shutting of the door of the room, supplying or not supplying abundance of air to satisfy the draft for the fire, would vary the pressure in the room so much as to cause the light to be nearly extinguished, or to blaze up violently.

Mr. Hodgson Jones said a batswing burner would not be employed for testing gas, although the union jet might be used for a very rich gas. The system generally practised in England was to adopt a very low pressure and an Argand burner. In France the burner was defined to be a Bengel burner of a prescribed form, in porcelain, with thirty holes, and a chimney 200 millimètres in height. There the standard was 42 grammes of oil, instead of 120 grains of sperm as in this country, and, consequently, the two lights were more nearly equal in intensity; whilst in England there was the disadvantage of one very weak light. The Author of the Paper appeared to be in favour of a standard more nearly approaching the gas to be tested, by which undoubtedly better results would be arrived at. He had used the single jet burner for eight or ten years, and in connection with the manufacture of gas it was invaluable, as a ready way of observing the quality of gas as it was made at the works. The principal thing to be attended to was to have the means of controlling the height of the flame. With a very delicate governor that could be done; and he believed that results thus obtained might be superior, as regarded accuracy, to the French method of testing, although in some respects the details used there were better.

Mr. W. H. Barlow wished to know whether, in the photometers described by the Author, provision was made for dis-

tinguishing the difference of colour in light. He had made some experiments in comparing common gas with the light produced by Bunsen's burner, with platinum wire, and he found a marked difference of colour in the light of candles and that of gas—one light being more yellow than the other; and this difference of colour rendered it difficult to say, which was the more powerful light of the two. He would like to know whether in these arrangements for measuring light any provision was made for distinguishing the colour of the light?

Mr. F. W. Hartley observed, that it was well known that there was considerable variation in the light given by candles; but no mention had been made in the Paper of a precaution which was adopted by practitioners of the photometric art: the careful selection of the candles with which to conduct experiments. Some sperm candles consumed as much as from 140 grains to 150 grains per hour, and several which had been alluded to in the Paper would never be used for laboratory purposes, as they were unfit for photometric experiments. The advisability of a better standard than candles had long been recognised; but he did not believe that the French system of photometry was superior to the English. He had made many experiments with Carcel lamps, and found the results vary so much, that, in his opinion, this lamp was not more reliable than candles. But Carcel lamps were not likely to be used for photometric purposes in England, because Mr. Keates had produced a lamp, which was a modified moderator, burning sperm oil at the rate of about 750 grains per hour; and that, as far as he had seen, promised to be a better standard than the one hitherto adopted. In so far as the jet photometer was concerned he admired the instrument, and admitted the general correctness of the principles on which it was based; but, at the same time, he had a conviction that it was not an instrument which should be used as a measure of the illuminating power of gas on behalf of the public. The value of its indications depended upon a comparison with some other standard. It constituted no specific standard in itself, and unlike the duration test had no specific value of its own. The duration test furnished a means of arriving at a positive commercial estimate of the value of gas, because, for a given height of flame, the consumption was determined; and therefore specific data were afforded for estimating the relative value of different gases. If the jet photometer were used in the way adopted by Professors Christison and Turner, Dr. Fyfe and others, that was, if the flame were in every experiment preserved at the same height, and the necessary expenditure of gas determined, it would be a valuable instrument for the scientific experimentalist. But then came another consideration, the effect produced on the public mind. The public used lamps and candles, and appreciated their

value. The public could also understand the value of a gas flame, when it was stated to give a light of ten, sixteen, or any number of candles; but the significance of a jet flame, produced under a certain pressure, would not be realised. Therefore, though the jet photometer was an excellent thing in the hands of the scientific man, it was not an instrument to satisfy the public. With all the precautions and care now taken in testing gas, by the competent operators who were recently appointed, the public were inclined to be suspicious; and if the jet photometer were used, it would be necessary to refer each instrument to some official to bring it into agreement with a standard; while the public would believe some jugglery was being practised, and would be more mystified than ever. If carefully applied no doubt the indications of the jet photometer would be of value, especially to the gas maker; but the least neglect would lead to error, and it was impossible to insure that the operators would be in all cases sufficiently careful. Under the ordinary photometric system a man might be convicted upon his own evidence of error. He did not advocate the retention of candles; but he thought the standard to be adopted should have some absolute value in light-giving power, and not be dependent, as the jet photometer was, on its relation to something else.

Mr. Henry Gore said, having devoted some years to the study of the manufacture of gas, and as photometry had now become an important branch of the professional practice of the gas engineer, he should like to say a few words upon the subject of the Paper. The determination of a reliable standard for photometry, was, to his mind, essential for the following reasons: because it should be a witness that could not prevaricate on the part of the judge, the accused, or the general public. He thought the evidence which the Author of the Paper had adduced, had placed the witness, whose evidence was now taken, in an untenable position, because it had been satisfactorily shown, that neither candles nor lamps were standards to which the question of the illuminating power of gas could be absolutely referred. The results of his experiments in photometry had taught him this—that any standard which was dependent upon mere visual observation was more or less open to defects, as to the evidence it furnished. Every one knew how delicate must be the nature of the observations by which to determine the relative value of two lights, and also the reflected light falling upon any surface. In reference to photometry, as applied to the estimation of the illuminating power of coal-gas, this defect was largely increased. In the first place, the standard was of comparatively low intensity, while the light examined was one of great intensity. If, for instance, with a Bunsen photometer, constructed upon the most perfect system, the image produced upon the semi-opaque disc by the gas was watched,

and then the image of the light produced by the candle, it would be found, after a few observations, that apparent identity of image became changed, and hence all sorts of errors crept in. But he thought the principal source of error was in connection with the material which was burned. He had had experience in the manufacture of what were called standard sperm candles, as during frequent residences abroad he was obliged to use candles manufactured on the spot; and he had found the chemical character of the candles to vary very much. The combustion of the candle was often materially changed by the density of the sperm being different in various parts of the candle, caused no doubt by the formation of crystals in the cooling of the sperm. Another source of error arose from the want of uniformity in the material or form of the wick. He believed, with Mr. Kirkham, that a candle burning uniformly 120 grains of sperm per hour, was a physical impossibility. If then this standard was open to so many objections, he thought it was not so satisfactory as to warrant its being adopted for determining the value of gas as between the producer and the consumer. The Carcel lamp experiments were open to the same objection. When in Paris in 1868, he visited one of the illuminating testing places there, and he was surprised to find the amount of correction necessary to be made even in the use of that standard. When the bulky character of the lamp was considered, the possibility of the balance becoming deranged, and the consequent error in the estimation of the quantity of oil consumed, another serious source of error might accrue, materially affecting the value of the results. If there was to be a test between the manufacturer and the consumer, it ought to be one which was of practical value, and which should be satisfactory to both parties. The consumer especially should feel certain that he obtained the maximum of light-giving material. Mr. Gore thought recourse might be had to simple chemical analysis to determine the quantity of illuminating matter in the shape of carbon in the gas; and he believed that was the only satisfactory standard and basis on which the results could be fairly judged.

Mr. Alfred Penny remarked that the Paper and the discussion upon it confirmed him in the conclusion he had long since come to, that but little was as yet known about the proper method of ascertaining the illuminating power of gas. It was impossible to have listened to the Paper, and noticed the great pains the Author had taken, without feeling that the methods followed were not satisfactory, or to be relied on. Many years ago, he came to the conclusion that the standard candle was not to be depended upon in any case; indeed he had never been able to procure candles that would burn exactly 120 grains of sperm

per hour. Now, that being the standard prescribed by Act of Parliament, it certainly seemed extraordinary that such an unreliable standard should have been submitted to for so many years. The experiments made by Mr. Kirkham, showed that—Parliament having prescribed a certain standard, and having put clauses into almost every gas bill rendering Gas Companies liable in heavy penalties if the gas was not maintained equal to a certain standard—Gas Companies might be very unfairly treated, by the mode adopted to ascertain what the illuminating power really was. On referring to the experiments, he found that, even where equal quantities of sperm were burnt, the light given by two or more candles varied to the extent of from 10 per cent. to 20 per cent., and that result would alter the standard to an extent which might lead to the imposition of penalties when not deserved. He would assume, for the sake of argument, that gas tested in the photometer room would burn at the rate of 5 cubic feet per hour, and during the experiment would remain of uniform illuminating power; but as the quality of the candles and the quantity of the sperm consumed were shown to be variable in every respect, the endeavour to ascertain the illuminating power of the gas, by the mode prescribed by Parliament, was defeated. He thought, therefore, that this was a matter which ought to have the attention of scientific men. It was clear to him that hitherto practice had been travelling in a wrong direction, and that the sooner science was invoked, to find out some true method of ascertaining the illuminating power of gas, the more creditable would it be to those interested in the subject. Reference had been made to the French system of testing, by the use of the Carcel lamp and of oil of a certain specific gravity. There was no doubt that if the wick could be kept right this would be better than candles; but he doubted very much whether the wick could be maintained in such a condition as would enable the Carcel lamp to be deemed a proper and reliable standard. No allusion had as yet been made to the difference of the human eyesight. Often as he had worked in the photometer room, he had never yet found his own experiments agree with those made at the same time by others. Indeed, it was rare to find two persons with eyesight exactly alike; and this was another reason why some different mode of testing the illuminating power of gas should be adopted, for so long as there was this human infirmity to contend with, so long would it be impossible for any two persons to arrive at the same conclusions. He ventured to think, having regard to what had been said, that recourse should be had to some chemical mode of testing the illuminating power, not dependent upon the eyesight, and not requiring mechanical means. He regarded this

as a question of great importance, and he trusted that a better mode of ascertaining the illuminating power of gas would be devised than that hitherto prescribed by Parliament, and which was known as the Parliamentary standard.

Mr. Upward observed, that there could be no doubt that the present mode of testing the photometric power of gas was very uncertain. He agreed with the suggestion that the illuminating value might be more accurately ascertained by some chemical process. For instance, of the hydro-carbons in gas produced from Boghead coal, 30 per cent. could be condensed by bromine. It had been ascertained by Mr. Frederick Evans (M. Inst. C.E.), the Engineer-in-Chief of the Chartered Gas Company, that the specific gravity of these products, which could be readily obtained, multiplied by the hydro-carbons condensable by bromine, gave the photometric power of the gas. In his opinion this afforded the best means of testing the quality of gas.

Although the jet photometer did not give the actual amount of illuminating power, it was nevertheless a useful instrument for the gas manufacturer, inasmuch as, with a certain sized orifice and a given pressure, a known length of flame was produced. He did not say it was a test by which the exact illuminating power could be positively stated, but it might be determined so nearly, that to the gas manufacturer it was a handy apparatus.

Mr. Brereton said, Acts of Parliament relating to gas undoubtedly opened the door to litigation if people were so disposed. Having been concerned for a Gas Company, he had taken some pains to ascertain what the parties interested had to do, as regarded the quality of gas to be provided. Gas Companies were liable to a penalty of £20 in every case where it could be proved that the Act had not been complied with, and to pay all the expenses of the inquiry. It appeared that 5 cubic feet of gas were to be equal in illuminating power to twelve sperm candles, six to the pound, burning at the rate of 120 grains each per hour. It was however beyond question that such candles were not now produced, but that the rate of consumption had increased from 120 grains to 135 grains per hour. There was no doubt that a more uniform standard for testing the illuminating power of gas should be provided. From all he could learn on the subject of the manufacture of sperm candles, it did not appear that any one had taken the trouble to make an article so uniform, as to be suitable for the purposes of a standard of comparison. He was informed that the increased rapidity of consumption was owing to a difference in the quality of the material; that, whereas, formerly, the older and more mature whales were caught and used by English merchants, who were responsible men employing their own ships, now the sperm was obtained from younger whales, principally through the

medium of America, and no one knew from what sperm the present candles were really made. At the same time, he did not see why, if the candles had increased in rapidity of burning from 120 grains to 135 grains per hour, that that need affect the uniformity of the standard. He did not believe that, for years to come, the English public would be satisfied with any other standard of comparison than the candle for ascertaining the illuminating power of gas; and under these circumstances, he thought an endeavour ought to be made to obtain a material which would give uniform results at the higher rate of consumption of 135 grains per hour.

Mr. Harrison, Vice-President, said, it appeared from the Paper and the discussion upon it, that Parliament, in its wisdom, had adopted a test which was no test whatever. He thought the question of gas was one of such importance, that it would be a matter of regret if some efficient substitute were not now proposed for the test which Parliament had adopted. He therefore expressed the hope that some of the members who had been practically engaged in this branch of the profession would give their views on this subject.

Mr. Jabez Church could endorse, from personal observation, all that had been said as to the present standard being imperfect and unreliable. He thought the Author of the Paper had not set forth all the defects in the present system. He agreed in the opinion that human vision differed very much; in fact, he had known a variation of a candle between five or six operators. Then the operation itself was bad, inasmuch as the burner seemed to be quite as important as the gas, for a burner had been brought forward which gave a result, it was stated, equal to two candles more, for a given quantity of gas, than the Parliamentary burner. No doubt, for the proper combustion of gas, different burners were required. He believed that gas of a low illuminating power, like London gas, must be burnt at a minimum pressure; while the Scotch gas, which was equal to thirty candles, could not be beneficially burnt in the same way, but under a much greater pressure. He thought all comparative standards were unreliable, and, in his opinion, the only means of properly determining the quality of gas was by chemical analysis, where the per-centage of hydro-carbons could be ascertained, and that, taken with the proper tests for purity, would form a reliable basis which scientific men could readily adopt.

Mr. Hodgson Jones said, the wick was a material element both in a candle and in a lamp. It was of course necessary that the sperm used for test candles should be as pure as possible, but if the wick was not properly made the candle would burn, more or less, according as the wick was formed. The same difficulty was found with the lamp in the burning of oil. The qualities of wicks were

very variable. He had found as much as from 17 per cent. to 25 per cent. difference in the consumption of oil burnt through different wicks. The French candle, ' Bougie de l'étoile,' was made of pure stearine, and was not therefore subject to the difference in quality referred to in the case of sperm. So many elements were involved in this question, that he doubted whether any absolute experiment, depending upon photometry alone, was the right test to follow as a commercial check on the quality of gas supplied to the public. The Author had stated in the Paper that the photometer test had been checked by the single jet and also by the duration test. Thus there were already two checks upon the photometrical experiments. The test of condensation (if it were not for the difficulty in manipulation) would be a good addition, but it was not so applicable to the poorer as to the richer gases. The gas stipulated for by Parliament in London was to have an illuminating power equal to fourteen or sixteen candles. These might be tested by the photometer and the single jet. The principal difficulties were, however, the corrections necessary for the experimenters, and the allowances for the variations in the human sight. If an observer was not very careful great mistakes might be made; but he doubted whether any serious discrepancies were found in the results of the testings by the official testers in London. They had been at work seven or eight years, and it might be assumed that they were competent to discharge the functions required of them. There was the same difficulty with the lamp test as with the candle test,—viz., the wick. Whatever material was burnt, it must be done by means of a wick. This was often badly formed, and unless a number of experiments were made, and the average taken, no reliable results could be obtained. He believed in France the amount of per-centage of difference in testing was rather less than it was in England, and that it worked satisfactorily there. True, the price of gas to the general public was lower in this country, although the standard of light was higher than in France; perhaps also the subject had been more discussed here. He thought it could not be argued that the photometric test was utterly unsatisfactory, especially if corrected by the means at the disposal of the chemists who were employed in the matter. Some of the first chemists had been engaged in testing, both in this country and in France, and he thought under the circumstances it was rather out of place for engineers to object entirely to the present commercial checks which were used for controlling gas supply.

Mr. Henry E. Jones gathered, from what had been said, that there was a feeling in favour of chemical analysis, to which he saw no objection, as he doubted whether the public would be so readily

satisfied. The frequent publication in the newspapers of the reports of analyses, made by eminent Professors, of the water supplied to the metropolis showed that it contained many tons of sewage contamination; but, notwithstanding these reports, the public continued to drink the water, from which it would seem to appear, that the public had little faith in chemical analyses. Anything like a comparison by the eyesight was regarded by the consumer as a practical test, and one in which confidence could be placed. At the same time, the candle was no doubt an uncertain and variable standard, and this remark applied to the Carcel lamp only in a different degree. It had occurred to him,—though he had tried no experiments with it,—that a piece of platinum wire, made luminous by heating to incandescence by a current of electricity, would afford a constant definite standard of comparison. He knew that this suggestion was open to several objections, the great intensity required not being the least, and also the different colour of the light emitted to that which was produced by gas.

Mr. G. Berkley remarked that what was called the English test appeared to be defective, inasmuch it was solely a photometric test, and the sperm candles burned were not analyzed. With the French test, on the other hand, the quality of the oil consumed was tested by chemical analysis; but it must be admitted that the fact of the material being burnt through a wick might vary the illuminating power. It occurred to him that, if the photometric test was not considered a perfect one by practical men, then it would be wise to take advantage of the aid of chemistry. He would also suggest whether, with a true analysis of gas, of a known illuminating power, such gas might not be the best standard by which to test the illuminating power of other gases.

Three or four years ago he heard Dr. Frankland state the results of experiments with a burner, which might be thus described:—The burner was made by placing round the chimney of an ordinary Argand burner a similar glass tube of somewhat larger size, which rested upon a plate of glass below the burner, so that the air passed to the burner down between the two glass chimneys, and became heated, and thus the gas lights were supplied with heated air instead of cold air. He had the authority of Dr. Frankland for stating, that the result of the trial with this burner, as compared with the ordinary Argand burner, was a saving of 33 per cent. of gas, with equal light, or that there was an increase of light of 62 per cent. with an equal consumption of gas.

Mr. William Atkinson referred to an adjunct to a burner with which many were no doubt familiar, namely, a thin piece of platinum. If a very thin film of platinum were placed between the two orifices of an ordinary burner the amount of light would be increased from 40 per cent. to 50 per cent. without any increase in

the consumption of gas. Thus it was quite clear, as had already been pointed out, that chemical analysis, 'per se,' was not a proper test for gas, because the light was so modified by the burner. It was manifest that if Parliament laid down a standard of candles, provision ought to be made for the supply of that particular candle: as there could be no difficulty in modifying the size of the wick, or in improving the quality of the sperm, so as to produce a consumption of exactly 120 grains per hour—a result which could not be hoped for so long as the candles were obtained from various manufacturers.

Mr. Vignoles, Vice-President, said it was evident, that in seeking for the best standard of comparison, either to create or to adopt, regard must be had to external lights, whether sperm, or oil, on the French system. He thought the task to which gas engineers should apply themselves was to fix upon some gas, under certain given conditions as to quality and pressure, as a standard of comparison for other gases. It appeared to him that the standard to be established should be based upon the article to be consumed; and he ventured to think there would be no difficulty in fixing upon a standard of illuminating power which should constitute the test to which other gases might be referred.

Mr. Wood, of Hastings, said, having been engaged for many years in experiments of a similar kind to those recorded in the Paper, he could confirm, generally, the results arrived at by the Author. He had found great want of uniformity in the rate of consumption of sperm candles, which in his experience varied from 116 grains to 130 grains per hour, but he had never met with candles which averaged 135 grains. In the case of fourteen experiments he assisted in conducting, in testing the gas at Manchester, the consumption of sperm averaged throughout all the experiments only 122·08 grains per hour. This was a closer approximation to the standard of 120 grains prescribed by Parliament than he had experienced in his private practice, as in this case the range was from 123 grains to 128 grains; and it was quite sufficient for him to agree with Mr. Kirkham in condemning candles as a standard of comparison for coal-gas. He was of opinion that, while perfect combustion was maintained, the ratio of light increased per grain of sperm consumed; that was, more light would be given per grain of sperm if 125 grains were consumed, instead of the standard of 120 grains. The consequence was the standard continually varied. He therefore thought it was quite time that endeavours should be made to obtain a more reliable standard. He believed the wick was the difficulty with the Carcel lamp; and he hoped the time would come, when the combination of the specific gravity with the jet photometer and chemical analysis would form a better standard than that at present in use.

Mr. Glover observed that, from his experience, he could not agree in the remark that the greater the consumption of sperm, the greater was the amount of light; for this reason, that the candle smoked, and then the proper combustion of the sperm was not effected. This question was one of great importance to an extensive interest. There was consumed annually in London alone £3,000,000 worth of coal-gas; and the way in which the Legislature had dealt with this interest had produced disastrous consequences to the capital invested in it. Scientific men had a difficulty in determining not only the quantity of gas, but the amount of light to be obtained from the gas; and Parliament singularly fixed upon one standard burner for all kinds of coal-gas. Nothing could be more unscientific, inasmuch as, according to the different qualities of the gas, various modifications of the burners were required. He was present at a Committee of the House of Commons, when the Rev. Mr. Bowditch and Dr. Letheby were requested to determine upon the burner which the Birmingham and Staffordshire Gas Company should adopt, and they were expected to do in half an hour what probably would have involved an experimental inquiry extending over half a year. It was unjust to attempt to fix one standard burner for all kinds of coal-gas. Every gas company ought to be entitled to obtain the largest quantity of light out of a given quantity of the gas they manufactured. He did not hesitate to say, if the Birmingham and Staffordshire Company's burner were used for some of the gas in London, it would bring down the illuminating power from fourteen candles to about nine candles. It was obvious that every company ought to be entitled to use the burner which would give the greatest amount of light for a given quantity of their own gas. The quantity of light given would vary according to the size of the openings and with the amount of pressure at the burner. The burner fixed by Parliamentary enactment was the Argand, with fifteen holes and a chimney of 7 inches in height. In the first place, as to the chimney itself, what did it do? It was composed of glass: now glass, it was well known, varied much in purity and in thickness; also, the glass chimney absorbed and reflected an enormous quantity of light. Every flame of gas that was to be compared with a standard light ought to be a naked flame. There was reflection of light from the inner and outer surfaces of the chimney, and the quantity of light absorbed by the glass amounted to a large per-centage of the quantity of light produced by the gas. Many sources of error arising from the Argand burner with its chimney would be avoided if a naked flame were employed,—say a batswing — which would consume 5 cubic feet per hour under a pressure of $\frac{5}{10}$ths of an inch. The size of the opening should be regulated by the quality of the gas; the richer the gas

the smaller should be the size of the opening in the burner, and the lower (within a certain limit) the pressure at the burner the greater the quantity of light. Some consideration ought to be given to the disastrous consequences to the gas companies with the enormous pecuniary interest involved, being restricted to one standard burner, and at the mercy of all sorts of experimenters, and all kinds of complicated apparatus, introducing various sources of error, and seriously interfering with the quantity of light to be computed for the gas produced by any company. Nothing could be more unjust or injurious to the interest, first, of the manufacturer, and then of the public. Next, with respect to the question of the standard of comparison with which the illuminating power of the gas was to be tested. It was either the Carcel lamp or the sperm candle consumed at the rate of so many grains per hour, which was generally adopted; and although both were open to objection, the Carcel lamp varied to a much greater extent than the sperm candle when properly selected. It might be remarked that, on the reading of the scales in the boxed photometer, different experimenters seldom gave the same results. The instrument was unnecessarily complicated. All would admit that simplicity was an element of perfection in apparatus for practical use. All that was required was a simple beam of 60 inches in length, accurately graduated, interposed between the candle and the gas burner, and a properly adapted screen for the reception of the image. Instead of this, the light was enclosed in a box. Could a candle burn in a box the same as in an open room? Did gas burn in a box the same as in an open space? By no means. Yet the Board of Trade Referees adopted the photometer closed in a box, and laid down rules diametrically opposed to science, by enclosing the lights in a condition that was not normal. The candle and gas should be burnt in a room properly ventilated. No box could be so supplied with air as to allow of the proper combustion of either.

It must be recollected that it was not only gas that was sold, but light, and in that respect both quantity and quality had to be dealt with. The quantity of gas could be accurately determined by the standards deposited at the Exchequer under the "Sales of Gas Act," and the cubic foot of gas was sufficiently defined in the second clause of the Act. In using the cubic-foot bottle, great care was required to avoid errors arising from the entanglement of air-bubbles in the distilled water, or the displacement, by agitation, of air that had been absorbed by the water; otherwise, in the use of the cubic-foot bottle, no two experiments would be found to agree. It was also necessary to disregard the first experiment with the dry bottle, and to record the successive experiments with the wet bottle, with the film of water it contained. His reason for referring to

this point was the importance of the subject, which he thought had not yet received the attention, either from scientific men or from Parliament, which it deserved. Gas had now become almost a necessary of life, secondary only to water; and to the poor man, light in this country really determined to a great extent the value of his labour. The more this agent was rendered accessible to all classes of the community, the better for the public interest. It was gratifying to find that Parliament this session was dealing with this subject in a manner more worthy of the interests involved. The point was to get a just measure of quantity and of quality. With regard to the measure of quantity, there was now at the Exchequer that which the Astronomer Royal had reported to the Lords of the Treasury to be one of the most correct standards in existence, in fact, as perfect as human art could make it. If any person, visiting the Standards Department of the Board of Trade, found out a more perfect method, no doubt the suggestion would be acted upon. He repeated, that Parliament had not acted wisely in endeavouring to fix a standard burner for all qualities of ordinary and Cannel coal-gas. In conclusion, he respectfully submitted that every company ought to be allowed to select that burner which gave the greatest amount of light with the consumption of the gas they manufactured; for, as the quality of gas varied, it was necessary also to alter the burner. He considered that sperm candles were superior to the Carcel lamp as a standard of comparison. In this country there was a tendency to attach too much importance to the greater scientific accuracy of the French; but theoretical refinement in the construction of instruments might be carried so far as to interfere with the accuracy of the practical results to be obtained from them; and while he admitted the theoretical precision of some of the French instruments, he asserted, without fear of contradiction, that English instruments, for practical purposes, were superior to any manufactured abroad.

Mr. A. G. Anderson, Professor of Practical Chemistry in Queen's College, Birmingham, said the high consumption of candles detailed in Mr. Kirkham's experiments struck him as remarkable. He recollected, however, that about a year and a half ago, when conducting some experiments in conjunction with Dr. Frankland, he had a difficulty in obtaining candles that would consume 122 grains to 128 grains per hour, because error was likely to creep into the experiments when candles were employed which consumed more than at the rate of 128 grains per hour. On that account he was always careful in the selection of the candles, and he had found that if he obtained those which consumed 122 grains to 128 grains per hour, there was not the same amount of error in the experiments as that which was given in the Paper as one of the results

obtained by the Author. Now, there could be no doubt, that a great deal of the error incidental to the prosecution of these experiments arose from the varying nature of the materials of which the testing candles were made. He believed it was customary for candle manufacturers to use variable amounts of paraffin, in addition to the sperm, and other materials. Then again, as had already been remarked, the wick unquestionably was a fruitful source of error; but in comparing the English system with the French, the English was far more liable to error, from the varying nature of the material, than if a more simple plan was adopted. With the system employed in the so-called refining of oils, he thought the same objection must apply to the oil-lamp test as to the candles, viz., the varying amount of light given when used as a standard of comparison. Allusion had been made to the desirability of adopting some standard which should be certain and uniform. It appeared to him, that the only way to arrive at an exact system was by first ascertaining the illuminating value of the candles. He thought that Parliament, in adopting candles as the standard, contemplated that which should be used by the consumer. There should be some standard to which the candles could be referred, or some exact system defined by which the candles should be made. It occurred to him, after all, whether it would not be better to fix upon a standard gas to be employed for these purposes. There were three or four well-defined qualities of gas with which he had made some experiments, to all of which the term 'marsh gas' had been applied. One was the 'marsh gas' produced by heating sodium acetate with baryta or lime. It had also occurred to him that this marsh gas might be so distilled as to furnish a gas that would have a very uniform character, with which the testing candles might be regularly compared. As to the suggestion that probably the only exact method of ascertaining the illuminating power of gas was by chemical analysis, he presumed the valuation of the hydro-carbons, to which the light-giving powers of coal-gas were known to be ascribed, was intended. Unfortunately, in ascertaining the quality or volume of hydro-carbons in gas, there was no indication of the exact density of these hydro-carbons: and he knew there was one circumstance, even supposing that difficulty could be overcome, which, nevertheless, would seriously interfere with any application of such data—gas always contained variable amounts of hydrogen and carbonic oxide. The proportions of hydrogen and carbonic oxide would more or less affect the illuminating value of the gas—for this reason: he had found that a given volume of illuminating gaseous hydro-carbons gave more light, when burned with a given volume of hydrogen, than when similarly consumed with the exactly corresponding volume of carbonic oxide Therefore, with a preponderance of hydrogen (which might, under normal

conditions, often occur), there would be less illuminating value in the gas, and, of course, the contrary with the substitution of hydrogen for the carbonic oxide. Consequently, it was evident the illuminating power of coal-gas depended on the nature of the so-called 'diluents,' as well as on its volume of illuminating hydrocarbons; so that the exact valuation of the last would, practically, be of no value whatever.

Mr. KIRKHAM said the candles employed in the experiments, as stated in the Paper, were purchased from six or seven different manufacturers, all of whom professed to make candles expressly for testing the illuminating power of gas. It would not have done to have selected and examined any particular candles, as he could not by that means have ascertained what the illuminating power would be. The candles were taken indiscriminately, and the consumption was found to vary from 118 grains up to 150 grains per hour. The result obtained from each candle was put on the diagrams as it happened: if a selection had been made, it might have been said it was done for a purpose. It would be observed that 135 grains per hour was the average consumption of the candles purchased at the present time. Professor Graham, and other eminent chemists, who made an elaborate series of experiments in 1852, had arrived at the same result. He did not think any one else had tested the candles in the same manner as he had done, for the reason that the gas was kept a constant. Most experimenters had used the gas as supplied to the public, without taking any pains to keep it constant. Again, there appeared to be an objection with regard to the difference between one operator and another, in respect to vision. He had taken the precaution to change the operators from one photometer to another every ten minutes, so as to get an average of readings (and thus reduce to a minimum any variations there might be in the vision of the operators), as well as an average of the consumption of sperm.

The question of the burner was one which was at present under consideration, and he hoped before long to be in a position to place on record a similar series of experiments to those now given on the subject of candles. The reason for adopting a lamp was, that although there was an error in the lamp, yet it was not multiplied to the same extent as the candle. For instance, suppose it was 14-candle gas, a candle would only give one-fourteenth of the amount of light emitted; consequently, in the necessary corrections, any error in the candle was multiplied fourteen times; whereas, with a lamp of nearly equal illuminating power to the gas, the truth would be much more nearly arrived at. Then, if that lamp was compared with the height of jet issuing from a given orifice at a certain rate, and the amount of light given by the lamp was compared with the height of the jet and the quantity consumed, or the dura-

tion test, he thought that would be something like what was required.

With regard to chemical analysis, no doubt in the hands of some chemists it would be an easy matter; but, as a rule, he did not think it would lead to very satisfactory results. He was not in favour of the bromine test. He had tried it in connection with these operations, and found it varied considerably, as even from the same gas several different results were obtained. If gas containing a little carbonic acid was treated with bromine, and if, as was usual, potash was added to remove the fumes of bromine, then a greater amount of condensation was obtained, in consequence of the carbonic acid present. If the potash was added first, there was the same disadvantage, because the potash would remove a certain amount of the illuminating constituents; consequently, no two results were alike. As matters stood at present, he thought there could be no better mode of testing gas than the one proposed—that was by a lamp (not necessarily a Carcel lamp) with a constant consumption, compared with the height of flame and the quantity of gas required to maintain that flame.

Mr. Gregory, President, was sure all would agree in the expression of thanks to Mr. Kirkham for his valuable Paper, and also to those who had taken part in the discussion. He thought every one must have come to the conclusion, that the use of the sperm candle, as a test of the power of gas-light, was a fallacious one, regard being had not merely to the irregularity of the wick and the introduction of foreign substances in the sperm, but even to the variable quality of the sperm itself.

While recognizing the improvements described by Mr. Kirkham, he thought other improvements might be expected; and, knowing the exact results of chemistry, and its wide application as a test, it might be hoped that some means would be discovered by which chemistry might be applied as a test of the quality and illuminating power of the light produced by gas. He thought that this was a direction of investigation to which they might fairly invite the attention of gas engineers, whose powers of practical and scientific investigation had been so well illustrated in the discussion.

April 20, 1869.

CHARLES HUTTON GREGORY, President, in the Chair.

The Discussion upon the Paper No. 1,222, "On the Standards of Comparison employed in testing the Illuminating Power of Gas," by Mr. Kirkham, occupied the whole evening, to the exclusion of any other subject.

April 27, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,216.—"On the Outfall of the River Humber." By WILLIAM SHELFORD, M. Inst. C.E.

SMEATON'S Appendix to his 'Narrative of the Edystone Lighthouse,' in which he describes the operations in the erection of the Spurn Lights, contains some important details relative to the condition of the Spurn Point at the time he wrote, and a sketch of his views on its previous history. With this exception, all historians of the locality have regarded the numerous interesting events at the mouth of the Humber from the antiquaries' point of view, and have evidently been conscious of their inability to deal with the physical causes of the events which they were recording. Under the impression that there is much to interest and instruct engineers in the history, not only of Spurn Point, but of the Humber Outfall, the Author presents to the Institution the facts which have come under his notice professionally.

The Estuary of the Humber is the outlet for the fresh waters from a larger drainage area than that of any other estuary in England, including, with some trivial exceptions, the whole of the district which is bounded by the watershed of the Tees on the north; by the eastern hills of Westmoreland and the watersheds of the Ribble, Mersey, and Severn on the west; by the watershed of the Avon on the south; by the watersheds of the Welland and the Witham on the south-east, and by the sea on the north-east; embracing, amongst others, the rivers Hull, Derwent, Nidd, Wharf, Ouze, Aire, Don, Idle, and Trent, with their tributaries, and the drainage of Ancholme, and containing an area of about 10,500 square miles, or one-fifth of the whole area of England. As the treatment of so large a subject must necessarily extend beyond the limits of one Paper, the Author proposes for the present to confine his remarks (except incidentally) to the district suggested by the positions of the towns of Bridlington, Hull, and Grimsby, and for convenience to arrange them under the following heads:—

I. The facts in connection with the past and present condition of the outfall, and of its peculiar feature—Spurn Point.

II. The ascertained alterations in the tidal régime.

III. The relative value of tidal and fresh water at the outfall.

IV. The relation of the operations of Nature and of engineering works to the facts recorded.

I. The facts in connection with the past and present condition of the outfall and of its peculiar feature—Spurn Point. The geological structure of the district consists of diluvial clay and gravel resting upon a substratum of chalk, which crops out and forms the range of hills called the Yorkshire Chalk Wolds, crossing the Humber into Lincolnshire at Hessle and Barton-on-Humber. A boring taken by Messrs. Easton and Amos (M.M. Inst. C.E.) in 1846 at Sunk Island shows that the top of the chalk is there about 110 feet below high-water spring tides, and Professor Phillips in his 'Geology of Yorkshire,' considers the "dip" to be eastward, at the rate of 20 feet per mile. The boring proves that the chalk is 20 feet below the bed of the estuary opposite to Sunk Island.

The principal of the diluvial accumulations which rest upon the chalk is "a mass of clay and pebbles which forms most of the hills and hard land in Holderness."[1] Of these the highest is Dimlington Height, rising 139 feet above the mean level of the sea. The surface of the country north of the Humber slopes for the most part downwards from the sea and drains into the Humber. Some of the clay hills have now become points of resistance to the force of the tides and waves; such are Dimlington Height, Clee Ness, and others.

There are marshes and fen lands of large extent adjoining and draining into the Humber, Plate 20. The first to require notice is from Patrington westward, to and beyond the river Hull, where about 60 square miles were formerly open to the flow of the tide. Its present level near the Humber is about 3 feet below high-water ordinary spring tides at sea, and at some points further inland it is 5 feet below. This marsh or fen was embanked at an early date, for a Royal Commission was appointed to see to the repair of its banks in 1313.[2]

Above Hull the first important fen is the narrow valley of Ancholme, containing about 50 square miles below the sea level, which Sir John Rennie supposes to have been embanked by the Romans. The surface of the ground near the Humber is now about 3 feet below high-water spring tides, while in the centre of the district it is 9 feet below.[3] This valley was shut out from tidal influence by a sluice made under the powers of an Act passed in 1769.

[1] Phillips' "Geology of Yorkshire."

[2] Dugdale's "History of Imbanking and Draining."

[3] *Vide* Sir J. Rennie's Paper "On the Drainage of the Ancholme," Minutes of Proceedings Inst. C.E., vol. iv., p. 186.

The great level at the confluence of the Ouze and the Trent contains an approximate area of 160 square miles below the sea level. The land near the Humber is 2 feet below high-water spring tides at sea, and 6 feet below it at some points farther inland. A Royal Commission was appointed for the repair of the banks in Hatfield Level as early as 1295, and subsequently for about a century Royal Commissions were issued for the repairs of the banks along the Ouze, the Humber, and the Trent, probably enclosing nearly the whole of the land now under cultivation.[1]

On both the Yorkshire and the Lincolnshire shores of the estuary other tracts of marsh land have been enclosed from time to time, and notably Sunk Island and Cherry Cobb Sands. They contain 9,500 acres, or about 15 square miles, at a level of 2 feet below high-water spring tides. The area of the Humber at high-water spring tides is 110 square miles, and the total area of reclaimed land in the estuary below high-water spring tides at sea is about 290 square miles.

Amongst other interesting information in connection with the Humber, it has been recorded by Mr. James Oldham (M. Inst. C.E.), in his Paper on the reclamation of Sunk Island,[2] and is otherwise known, that the whole of the east coast of Holderness, from Bridlington southwards, has been from the earliest historical times abraded and destroyed by the sea, and that the average width of land thus lost is $2\frac{1}{4}$ yards per annum. The cliffs consist of the clay and shingle before alluded to, which fall in large masses and are broken up by the heavy waves which on that coast accompany the north-east gales and act obliquely on the shore, transporting the shingle southwards[3] to the end of Spurn Point, where it meets with the powerful ebb of the tide from the Humber, and is carried out to sea.

Without going back to the time of the Romans, there can be no doubt that a thousand years ago, at the landing of the Danes in Holderness, Spurn Point projected much further to the eastward than at present, and if the average waste of $2\frac{1}{4}$ yards per annum be adopted (which is most likely insufficient), the projection must have been 2,250 yards at least beyond the present coast-line. The promontory might then have been a short point, having an ebb channel close to it, and if so there would be a good roadstead on its west side.

It is thought that at or near this spot the Danes landed in 867, and planted their standard, 'the Raven;' and here afterwards

[1] *Vide* Dugdale's description of their positions.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 454.

[3] *Vide* Paper "On the Motion of Shingle Beaches," by H. R. Palmer, Esq., F.R.S., C.E., Phil. Trans. 1834, p. 567.

gradually rose the town of Ravensburg, or Ravenser, or Ravenseret —(syret, in Saxon, meaning a place of shelter),—within Spurn Head. This town is remarkable as having been one of the most wealthy and flourishing ports of the kingdom. It returned two Members to Parliament, assisted in equipping the navy, had an annual fair of thirty days, two markets a week, is mentioned twice by Shakespear,[1] and considered itself honoured by the embarkation of Baliol with his army for the invasion of Scotland in 1332; by the landing of Bolingbroke, afterwards Henry IV., in 1399; and by the landing of Edward IV. in 1471—not long after which it was entirely swept away. The only trace of it which now exists is a stone cross of very elegant design, in decorated Gothic, about 16 feet high, supposed to have been first erected on the spot where Bolingbroke landed. After several removals, it is now in the grounds of Mr. Watson, of Hedon.

One peculiarity in the history of this place is the great number of names by which it was known at different dates; and a closer examination suggests that these names indicate corresponding changes in the condition of Spurn Point.

In 1251 some monks obtained half an acre of ground on which to erect buildings for the preservation of fish in the burg of Od, near Ravenser (Od meaning in Saxon a distant or out-of-the-way place). The Chronicler of Mœux Abbey,[2] near Hull, says, "Od was in the parish of Esington, about a mile distant from the mainland. The access to it was from Ravenser by a sandy road covered with round yellow stones, scarcely elevated above the sea. By the flowing of the ocean it was little affected on the east, and on the west it resisted in a wonderful manner the flux of the Humber." The two places were subsequently spoken of as one, and increased in importance, for in 1273 there was a dispute about a chapel at Od, in which the Archbishop of York was arbitrator. In 1285 the merchants speak of Ravens*road*; and in 1289 the Grimsby people are jealous, and claim certain privileges, calling it an island, and probably basing their claims upon its previous insular character. In 1310 the three shipping ports of the Humber whose merchants contributed to the navy were Hull, Grimsby, and Raven*ness*. In 1332 Baliol "took the sea at Ravens*purgh*." In 1346 a grant to the abbey at Mœux specifies the manors of Salthagh, Tharlesthorpe, Frismersk, Wytheflet, Dymelton, and Ravens*rodde*, the termination rodde, or rood, a cross, being more in accordance with the ideas of the monkish chronicler than the "road" of the merchants. The grant also says that they were on the bank of the Humber and on the sea-shore, and complains that their annual

[1] In 3rd part of King Henry VI., act 4, scene 7; and in Richard II., act 2, scene 1.

[2] Liber Melsæ. *Vide* Poulson's "History of Holderness."

value was reduced from £250 to £20, and, "what is worse, from day to day these places become so far waste, being tossed by impetuous waves every day and night, that within a very short time it may be feared that they will be altogether destroyed and consumed." And this must have occurred, for the only trace of their position is Salthagh Grange.

In 1347 "Ravensrod, in Holderness," was often inundated by the sea. In 1355 the bodies were washed out of their graves in the chapelyard of Ravenser. In 1360 "Ravenser Odd[1] was totally annihilated by the floods of the Humber and inundations of the great sea." In the reign of Richard II., 1376—99, Ravenser no longer sent Members to Parliament. In 1399 Bolingbroke landed at Raven*spore*, or Raven*spurgh*.[2] In 1413 a monk obtained a grant to erect a hermitage at Raven*scrosbourne*, but this name is only interesting in connection with the cross previously mentioned. In 1428, Richard Reedbarowe, the hermit of the chapel at Ravens-er*sporne* (Sporne, Spurn, Spuren, Spyrian—in Saxon—to look out), obtained a grant to take tolls from ships for the completion of a tower which he had already begun as a lighthouse.

In 1471 Edward IV. landed "within Humber, on Holderness side, at a place called Ravenspurgh, even in the same place where Henry Earl of Derbie, after called King Henry IV., landed."[3] About 1552 Raven*spur* is alluded to by Leland in his "Itinerary"; but Holinshed, in mentioning Kelsie Cliffe, Patenton Holmes, Pall, Hidon, and many other "ports and creeks," omits Ravenspurn, which probably then had no existence. Holinshed died about 1580.[4]

In 1622, Callis, in his Lectures on Sewers at Grays Inn, says that, "Of late years parcel of the Spurnhead in Yorkshire, which before did adhere to the continent, was torn therefrom by the sea, and is now in the nature of an island."

In 1676 a patent was granted by Charles II. to a Mr. Angell for the erection and maintenance of certain lights at Spurn Point, which lights were erected at the request of those interested in the northern trade, who represented that a broad long sand had been thrown up at the mouth of the Humber six or seven months before. Smeaton thought that this sand had afterwards become connected with the mainland, and so formed the Spurn Point of his day.[5]

About 1684, Captain Greenville Collins, hydrographer to King Charles II., made surveys and charts of fifty British ports, and,

[1] Liber Melsæ. Poulson's "Holderness."
[2] Thompson's "Holderness."
[3] Quotation, Thompson's "Ravenspurn."
[4] Thompson.
[5] Smeaton's "Appendix to Narrative of Edystone Lighthouse."

among others, of the Humber from the sea to Hull. This chart is in several hands at the present day, and, as it forms an epoch in the history of the Humber, it will be well to pause and refer to other points of interest, antecedent to the date of its publication.

Of these the first is—

Sunk Island.—In 1667 it was first spoken of as a novelty, and was then "reported to have been at first a great bank of sand (of which there are still many to be seen in the Humber at low water), that thereat other mud and matter stopt, and then still more and more, until it arrived at its present bigness." This was written in 1711,[1] and Greenville Collins's survey nearly represents its condition at that time. It is now the property of the Crown, and it is said that the title rests on the fact of its having been an island.

Frismersh, Frismersk (Fresh, or New Marsh), is supposed to have been on the site of Sunk Island, or eastward of it. In 1341 a Commission was appointed for viewing and repairing the banks on the coast of Humber in the towns of Patrington, Frismersh, Ottringham, &c.; and again in 1343.[2] In 1345 the charge of supporting the banks and sewers in Frismersh had become very burdensome, and the inhabitants petitioned the King that their lands were often overflowed by the tides of the Humber.

In 1361, Commissioners were appointed to view the banks on the coast of the Humber between Hessle and Ravensere.[3] Frismersh was probably not destroyed before 1362.

Clee Ness.—This promontory no doubt formerly projected farther into the Humber than at present. The cliff consists of stiff clay, and receives now, as it must have done for hundreds of years, the full force of the flood tide as it enters the Humber. One of the townships of Clee has gone to decay,[4] and it may be inferred that it has fallen a victim to the waves of the estuary.

The Old Den (Den, in Saxon, a valley or dale), is a hard bank of shingle within Spurnhead and at half-tide level. It has been supposed that Ravenser-Od stood there, or near to it,[5] but this is doubtful, and the Author is of opinion that it may consist of shingle which has been brought round the point by the flood tide, and has not been returned by the ebb.

Greenville Collins's Chart, 1684. (Plate 20.)

This chart shows Angell's Lights at Spurn, a low-water channel between Sunk Island and the north shore,—the main channel,

[1] Thompson.
[2] Dugdale.
[3] Dugdale.
[4] Allen's "History of Lincolnshire."
[5] Thompson's "Ravenspurn."

broad, and deep, running to the north of the Bull Sand, a small and shallow channel to the south of the Bull Sand. Sand Haile, Clee Ness, The Den, Trinity Sand, Long Middle, Burcum and others are shown. The soundings in deep water are generally few, but eastward of the Spurn they are very close, and show a depth of 3 fathoms to 9 fathoms.

After 1684 the Point continued to increase in length, and the lights consequently became useless. An application was therefore made to Parliament in 1766, by the Trinity Houses of Hull and Deptford-Strond, for power to erect and maintain other lights, and was passed. At this juncture Mr. Smeaton was consulted, and recommended the erection of two lighthouses.

Mitchell's Chart, 1778. (Plate 20.)

Twelve years after Smeaton was called in, a chart was published by a Robert Mitchell, and dedicated to the Trinity House of Kingston-upon-Hull. It shows the old lights extinguished, and two temporary lights erected at the Point, which has extended a mile further south. The low-water channel between Sunk Island and the mainland has silted up. The channel to the north of the Bull Sand has diminished, while that to the south of it has increased in importance. The Den, Trinity, and other sands have undergone great changes, while to the eastward of Spurn, large sands and shoals have formed.

In 1771, Smeaton reported that Spurn Point had extended 280 yards since 1766, and that it had increased on the Humber side, but diminished on the sea-side to the extent of 50 yards. In the same year Smeaton's small lighthouse was founded, and in 1772, his great lighthouse, which is the present "high light," was commenced. The small light appears to have been in danger from the first.[1]

In 1786, Smeaton made a survey of the Spurn, from which it appears that the high light was 1,840 yards south of the position of one of Angell's lights, and was then 480 yards from high-water mark at the end of the point, and that the Point had also moved westward throughout its length. Smeaton concluded that Spurn Point was a necessary appendage to the cliffs of Holderness, and was in a continual state of travel southward and westward; the southward movement being accompanied by a corresponding encroachment of the river on the Lincolnshire coast, and the westward movement by the abrasion of the coast of Holderness by the sea.[2]

[1] *Vide* Smeaton's "Reports."

[2] *Vide* "Appendix to Narrative of Edystone Lighthouse," and the plates and notes in explanation of them.

Hewett's Chart, 1828. (Plate 20.)

The next chart of value is the Admiralty chart, from the survey of Captain Hewett, R.N., and dated 1828. It shows that about 7,000 acres of the accretions at Sunk Island had been reclaimed, that the Point had advanced, and that the capacity of the channel to the south of the Bull Sand had again increased. Other changes had taken place, especially seaward of Spurn, where the accumulations of sand and stones had increased, and a light vessel had been moored in 1820. There is also a note on the chart, that a portion of the Spurn Neck, north of the lighthouses, is overflowed at high spring tides.

In 1849, a large breach occurred in the Spurn Neck, north of the lighthouses, and in 1850, Captain Vetch, R.E., held an Admiralty inquiry on the spot. He reported in favour of strengthening the point on its seaward face, by means of groynes placed at right angles to its length, for the purpose of intercepting the shingle in its passage southward, and on the Humber side by the further reclamation of the accretions east of Sunk Island.

Some of the groynes have been executed since 1863 by Mr. Coode (M. Inst. C.E.), and Captain Vetch's anticipations have been so far realized. But his plan has not been completed, and it is thought that the ultimate effect of converting the natural westward, or retiring movement of Spurn into an eastward or advancing one will be to bring about its destruction.

Calver's Chart, 1852. (Plate 20.)

This is the Admiralty chart at present in use. It was surveyed in 1851—2 by Captain Calver, R.N., (Assoc. Inst. C.E.), and is an excellent survey. It shows that 700 acres had been added to the reclamations of Sunk Island, and that the bay between Sunk Island and Spurn had become further silted up. The concavity in the Lincolnshire shore, opposite Spurn, and below low water, had increased, and the Middle Sand had shifted considerably. The mariner is warned in a note that it "is liable to change," and the soundings between it and Spurn are corrected to 1862.[1] Seaward of Spurn there does not seem to have been much alteration since 1828.

The flood and ebb streams are shown by dotted lines on this chart. Their direction was ascertained by the Author, and after-

[1] Since the above was written, the Author finds that part of the chart from Spurn to Sunk Island was corrected in 1866. The deductions in the Paper are based on the chart corrected to 1862, and are not materially affected by the recent alterations.

wards confirmed by independent observations, conducted by Mr. Coode in 1867. The main stream of the flood tide sets from the north-east against the Lincolnshire shore, which it scoops out, and rebounding against Clee Ness, is thrown across the Middle Sand into the Sunk Road. At the same time, another stream sets in round Spurn Point, up the Hawk Road and the North Channel. At about quarter-flood, when the low part of the bay, to the west of Trinity Sand, is covered, a branch from the main stream sets into the bay and returns down the North Channel, forming an eddy opposite the lighthouses. This current continues for three-quarters of the flood tide, and the North Channel has consequently a "three hours' flood and a nine hours' ebb." It is this eddy also which keeps the North Channel from silting up. The main ebb stream passes through the Fairway abreast of Sunk Island, and out to sea by the end of Spurn Point, and to the north of the Bull Sand, with a velocity of about 4 knots per hour. "The set of the tide when ebbing from the bay is south-south-west, and not through the North Channel until the Trinity Sand begins to uncover, which takes place somewhat after half tide."[1]

There is no perceptible current at any time of the tide on the north-east side of the line *a*, *a*. The land in the bay consists of warp and sand, more or less fine according to its exposure to currents. The average level is about half tide, and from careful levels taken over an area of a mile in width from the shore, under the direction of Mr. Coode, Mr. Oldham, and the Author, it appears that it rose, as a whole, 11½ inches between 1854 and 1867.

Movement of Spurn Point. (Plate 20.)

The following is a summary of the known extensions of Spurn Point southward:—

1676 to 1766	1,800[2] yards, or	20 yards per annum.
1766 „ 1771	280 „ „	56 „ „
1771 „ 1786	150 „ „	10 „ „
1786 „ 1851	300 „ „	4·6 „ „
1851 „ 1864	113 „ „	8·7 „ „
Total .	2,643 yards.	

The westward movement has been nearly uniform throughout the length of the Point.

Angell's Lights are known to have been swept away by the progress of the sea, and one of them is so shown in Smeaton's

[1] Mr. Coode, in his report to the Board of Trade, 1867; also Captain Calver, in his evidence before Court of Referees, 1866.

[2] This is only an approximate measurement, as the exact distance from Angell's Lights to the end of the Point, in 1676, is not known.

survey of 1786. The following summary of the history of Spurn Lights will serve to prove the amount of this movement from time to time.

Smeaton's small lighthouse was built in 1771, 280 yards east of the High Light.

A second was built 70 yards farther west in 1816.
A third „ 30 „ still farther west in 1830.
A fourth „ 50 „ „ 1831.

And in 1863 the sea had reached the High Light itself, making a total westerly advance of 280 yards in ninety-two years or 3 yards per annum. The Low Light now stands on the Humber side of the High Light.

At the present time, Spurn Point consists of a bank of sand and shingle, having a top varying in width from 9 feet at its northern end to 500 feet at the Lighthouses.

By means of blown sand and 'bent grass,' it has attained a maximum height of 20 feet above high-water spring tides, but its minimum height scarcely reaches above that level. The slopes vary from 2 to 1 to 20 to 1.

II. The ascertained alterations in the tidal régime.

1st. As to range—In 1344 the roads between Howden and York and Selby and York were frequently flooded, and the banks were too low to keep out the tides.[1]

In 1357 the inhabitants of Hull informed the king (Edward III.) that the tides in the Humber and the river Hull flowed higher by 4 feet than they had been accustomed to, and, in consequence, the road from Anlaby to Hull, and the lands between those places and Hessle, were continually destroyed.[2] About the same time, the men of Ravenspurn wished to remove to Drypool near Hull; but as Drypool and the adjoining lands had been greatly injured by the overflowing of the tides, they were obliged to go to Hull.[3] Dugdale says, "How long the tides upon this coast kept their course so much higher than they had formerly done I am not able to say, but it is like that they did so for no short time after, there being scarce a year in the succeeding part of this king's reign (20 years), that one or more commissions were not issued for repair of the banks upon this great river." In 1684, Greenville Collins, in his "Sailing Directions," gave the rise of spring tides at Hull as 17 feet.

In 1725, an accurate survey was made of the Ouze from its source to the sea, by William Palmer and Partners, of York, and on

[1] Dugdale's "Imbanking."
[2] Dugdale's "Imbanking;" Gent's "History of Hull;" and Tickell's "History of Hull."
[3] Gough's "Camden;" Thompson.

the same sheet was engraved a diagram of the tides from the sea to York, based on the common report of the watermen. This survey and diagram are accepted as generally authoritative. The diagram shows a rise at spring tides of 21 feet at sea and 18 feet at Hull, *i. e.*, 3 feet less at the latter. The tide in the Ouze was then free to flow. It was afterwards shut out of the upper portion of the river by the construction of Naburn Lock in 1754.

In Thompson's history of Ravenspurn, published in 1822, the following occurs: "In late years persons who live in Hull and the neighbourhood have observed considerable variations in the flowing and ebbing of the tides in the Humber. In many instances the water has arisen above the banks within which it has usually been confined, and has done great damage to the adjacent country; and in ebbing, it has fallen so low in its channel as to leave visible wrecks of vessels and other sunken matter of various kinds, never before seen by any person now living."

Captain Hewett's chart of 1828 gives a range of 23 feet at sea, and 22 feet at Hull, *i.e.*, 1 foot less at the latter. Captain Calver's chart, now in use, gives a range of 18 feet 9 inches at sea, and 20 feet 10 inches at Hull, *i.e.*, 2 feet 1 inch more at Hull than at sea. The tidal range at Hull increased therefore 3 feet between 1852 and 1828, and 2 feet between 1828 and 1725, making 5 feet since 1725; and if the increase has been continuous since the rise of 4 feet mentioned in 1357, it would amount to a total of 9 feet in about six hundred years.

In 1864 a report was made to the British Association by a Committee, consisting chiefly of members of the Institution, on a series of tidal observations, taken between the 9th May and the 6th June, 1864, at intervals of fifteen minutes at Hull, Goole, Naburn Lock, and Gainsborough. The Author has been able, by the kindness of Mr. E. H. Clark (Assoc. Inst. C.E.), to supplement them by observations taken at high and low water on the same days at Grimsby. A copy of the latter is appended to the Paper. These observations prove the correctness of the variation between the ranges of tide at Hull and Grimsby, as shown in Captain Calver's chart.

On the 21st of April, 1866, observations were taken, under the Author's direction, at intervals of ten minutes, on the times and heights of one mean tide at Hull Docks and the Spurn Lights (Humber side), and they were connected by levels from ordnance bench-marks. Although he attaches little importance to such a limited experiment, he gives the facts in the Appendix.

In 1868, on the 8th of February, during a strong north-west wind, the tide rose higher by 2 inches than any which had been recorded in the ninety years previous. It reached 30 feet 5 inches on the Hull Dock gauge, or 15·7 feet above ordnance datum.

Fig. 2, Plate 21, is a diagram of some of the tides above referred to. Those of 1725 and 1828 are plotted from high water as a horizontal line, and those of 1864 from ordnance datum.

The effect of Naburn Lock on the tide in the Ouze is very noticeable. The tide in the Trent is shown by short dotted lines.

2nd. As to capacity.—The charts of Hewett and Calver show discrepancies in tidal range which require explanation. Captain Hewett was unfortunately lost at sea, and the datum line of his soundings is not accurately known;[1] but, as the 23 feet which he gives is about the rise of an exceptional spring tide at Spurn, and as it is obviously safer for nautical purposes to assume a low low-water line, and thus to show the depths as small as possible, his reasons may be inferred for adopting an extraordinary tide as his standard. Captain Calver, on the other hand, according to Admiralty instructions, gives the tidal range at about full and change of the moon, although it is well known that the highest tides on the east coast occur two days later. The discrepancy, which is serious, amounting to 4 feet 3 inches at sea, disappears if the mean level of each tide at sea be used as a common point by which to fix the relations of the various tides to each other with tolerable accuracy. At Hull the difference is further complicated by the improved range since 1828.

The cross sections of 1828, Plate 21, in which an approximation is required to "reduced levels," are plotted from a high-water line 2 feet 1½ inch above Calver's high-water line, making low water 1 foot above Calver's low-water line at Hull, and 2 feet 1½ inch below it at Spurn. But in the longitudinal section, Fig. 1, Plate 21, in which a comparison between the low-water channels is desired, a correction of 2 feet 1½ inch has been made throughout. In corroboration of the difference which has thus been assumed, it may be stated that Captain Calver fixed low-water ordinary spring tides at 6 feet 2 inches on Grimsby Dock gauge, and that very exceptional tides ebb out to 4 feet on that gauge.

Fig. 1, Plate 21, is a longitudinal section on the deep channel lines of 1828 and 1852, plotted from the depths on the charts of those dates, after correction of the low-water line as above described. It shows a general deepening of the river, except at a point above Sunk Island and beyond Spurn Light Vessel, at both of which places the depth has diminished.

Plate 21 also contains a selection from a series of cross sections, plotted from the charts of 1828 and 1852, after correction of the low-water line as above described. These show the capacity of the estuary

[1] Captain Calver, in his evidence before Court of Referees, 1866.

below low water from Hull to the sea at the respective dates, and the results may be summarized thus:

Seaward of Spurn Point there has been no appreciable alteration. At Spurn Point, a gain since 1828 of 11·7 per cent. Between Spurn Point and Sunk Island, a gain of 6·2 per cent. Opposite Sunk Island, a gain of 32·5 per cent. Opposite Foul Holme and Paull Sands, a gain of 4·5 per cent. Between Paull and Hull, a gain of 25·5 per cent., making a total gain of 11·7 per cent. between Hull and Spurn.

The perfect accuracy of each of the above comparisons is not relied upon, but the following general conclusion is believed to be inevitable, viz.: that the tidal capacity of the Humber below low water increased between 1828 and 1852.

III. The relative value of tidal and fresh water at the outfall. The drainage-area of the Humber has already been stated to be 10,500 square miles. A rainfall of half an inch over it would give 450 million cubic yards. The tidal capacity of the Humber and its affluents is about 1770 million cubic yards. The Author is not aware that any connected observations of the heights and velocities of the tides in freshes and in droughts have ever been taken on the Humber. There are men, however, who, from long association, have become close observers of the condition of the estuary under all circumstances, and their evidence agrees in this; that in droughts, the sands from the Ouze and the Trent down to the Skitter Sand below Hull are raised in height and lengthened at their upstream ends, and that the flood channels are then deeper than the ebb; also that in freshes the same sands are depressed in height and lengthened at their downstream ends, and that the ebb channels are then deeper than the flood. They concur in opinion, that the height of low water from Hull to the sea is much more affected by winds than by freshes, but that in freshes the velocity of the ebb increases. They are not agreed as to the comparative velocities of the flood and the ebb.

The Author is of opinion, that whilst there is a wide field open to any one who will undertake the investigation of the phenomena connected with the discharge of so large a volume of fresh water as that which pulsates through the Humber to the sea; yet at the outfall there are other forces at work, of sufficient magnitude to throw into shade the effect produced by occasional freshes acting directly upon it.

IV. The relation of the operations of Nature and of engineering works to the facts recorded.

The Humber abounds in examples of engineering works; such as the numerous embankments, drains, and sluices, for the recla-

mation of its marshes, the lighthouses at Spurn, the docks at Grimsby and Hull, the lock at Naburn, and many others. It may be said broadly of them all, that where their intention or effect has been anything more than local, it has always been in the direction of encroachment upon the tidal area, and it may be as broadly stated that, notwithstanding this encroachment, the tidal action of the estuary has continuously improved up to the present time. Nor are the causes far to seek, or much open to conjecture.

At the founding of Ravenser about 867, the estuary was doubtless of greater width at high water than at present, and of less depth. The flood channel would then, as now, be on the south shore, and the ebb would set near to the north shore, and close past the point of the promontory. The flood tide would wear away a concavity in the south shore, and a similar action to that which made the Bull Sand would, in course of time, form a large sand, which, like Sunk Island, might accumulate till it was dry at high-water mean tides. But as the flood tide continued to wear into the Lincolnshire shore, so would the north or ebb channel become weaker; until, being no longer able to transport the shingle thrown up by the sea, it would be closed by its rapid advance, and a neck would be formed, having the sand or island, upon which Ravenser-Odd was afterwards built, for its southern termination. Sand would be blown by the wind, and shingle would be thrown up by the sea, and thus the island would be raised and strengthened for a time. The diversion of the ebb into the flood channel would deepen it, and there would be a good roadstead inside the Point.

The Author believes that Spurnhead was in this state in 1250, that neap and mean tides flowed in nearly the same channel above Hull as at present, but that up to that time spring tides overflowed the marshes, the banks of which were evidently, for the most part, neglected, and that the high-water line spring tides of the estuary scarcely attained the sea-level. But when the mouth was narrowed by the connection of the island with the land, and the ebb and flow confined to one, or, at least, to fewer channels, and when, moreover, the marsh banks had been restored and the accretions in the closed channel to the north, which were called "Freshmarsh," had formed, the high-water line in the upper reaches not only attained the sea-level but rose above it. A depression of the low-water line followed, and thus, in the next century (1350), there might easily be an increase of 4 feet in the tidal range at Hull, if low-water mark were taken as the standard from which to measure, as it probably was. The increased range produced greater depth, and, consequently, greater velocity, and the position of Ravenser-Odd became rapidly weaker. Its mercantile population removed to Hull (about 1357), and, at last, the town was carried away altogether in 1360, leaving, however, a bank of shingle called Raven-

spurgh, which might still serve as an excellent pier or landing-place to the then declining town of Ravenser; and on this Spur, or more likely in Ravenser itself, stood the cross supposed to commemorate the landing of Bolingbroke. The banks of Fresh-marsh, and the marsh itself, were probably destroyed by the increased tidal scour, and by the greater force of the current of the flood tide which the alterations at the mouth might throw upon them.

There was, however, another force at work—"the great sea." The degradation of the coast of Holderness had arrived close to the town of Ravenser, which had been protected, in all probability, hitherto, by a high clay cliff and by the Spurn Neck. But now its doom is come. The cliff is gone, and, in 1355, the Spurn Neck is attenuated. Soon the dead are washed out of their graves. The general monotony of the place is relieved by the landing, in 1399, of a duke about to take England's throne. A monk, true to his charitable profession, begins a lighthouse, in 1428, to show the mariners the way to the rival port of Hull, but has not the means of finishing it. Another king lands, in 1471, and his chronicler only calls the old town a "place." Gradually, but at last, the Spurn Point is outflanked; all trace of the town is washed away by the force of the waves, and the sea removes Spurn Point bodily a little further west. But it is a slow process. The head is again an island, in 1622, and most likely soon became a sand, invisible at high water, and the tidal action of the estuary may then have declined. The cutting into the Lincolnshire shore still goes on, and, in 1676, the sea again throws up sand and shingle, first as a shoal, afterwards by connecting it with the main land, as a neck in the form shown by Greenville Collins and described by Smeaton.

The old action is repeated as the new flood channel, south of the Bull Sand, opens, the tide in the ebb channel grows weaker, and is followed (about 1771) by the rapid lengthening of Spurn Point, increased range of tide, greater depth, greater velocity, rapid accretions in the North Channel and at Sunk Island, until the area of the estuary has become so small, and the forces at work in it so great, that the island, now Bull Sand, cannot lift its head even above low water. The same powers are at work at the present day. The channels abreast of Spurn are travelling southward. Meanwhile the sea is encroaching on Holderness, and will as surely outflank and remove the Spurn as it has done before.

The low-water channels up to Hull are now comparatively straight and confined, and the action of the ebb tide is therefore better than ever; but the shingle continues to creep along the shore to the end of the point, endeavouring still to close the estuary, but, foiled, retreats to the sea, and lies quietly out of the current, biding its time.

The thanks of the Author for much valuable information, and for many opportunities of acquiring it, are due to Sir Thomas Aston Clifford Constable, Bart., the present Lord of the Seigniory of Holderness, to Mr. Watson, of Hedon, Mr. Wyse, of Malton, Mr. E. H. Clark, C.E., of Grimsby, Mr. James Oldham, of Hull, Mr. R. T. Cussons, the Librarian of the excellent library at Hull, Mr. Luke Thompson, of York, and to many personal friends in London and elsewhere.

The Paper is accompanied by a series of Diagrams, from which Plates 20 and 21 have been compiled.

Copy of Tidal Observations taken at Grimsby (Royal Dock) in May and June, 1864. N.B. Zero of Gauge, 15·003 feet below Ordnance datum.

1864. Date.	Morning. Moon's Age.	Wind.	Water at Gauge.	Time.	Height.	Afternoon. Time.	Height.	Wind.	Water at Gauge.	Rise and Fall of Tide.	Observations—Barometer.
	days hrs.		ft. in.	hr. min.	ft. in.	hr. min.	ft. in.		ft. in.	ft. in.	
May 9	3 5	East; E.S.E.	25 6	1 40 7 40	8 8 25 6	2 0 8 0	7 10 25 0	E.S.E. ,,	25 0	17 2	Hard gale. Squally. B. 29·80.
,, 10	4 5	E.N.E. ,,	25 0	2 20 8 20	9 6 25 0	2 40 8 40	8 6 24 6	E.N.E. East.	24 6	16 0	Fresh and cloudy. B. 29·95.
,, 11	5 5	East. ,,	24 1	3 0 9 0	10 6 24 1	3 20 9 20	9 3 23 3	,, E.N.E.	23 3	14 0	Strong and cold. B. 30·00.
,, 12	6 6	N.E. ,,	23 6	3 45 9 45	10 6 23 6	4 6 10 15	9 10 22 0	,, N.N.E.	22 0	13 0	Light wind and fine. B. 29·92.
,, 13	7 6	N.N.E.	22 3	4 30 10 30	9 8 22 3	5 0 11 0	10 9 21 3	N.E. ,,	21 3	10 6	Fine breeze and clear. B. 30·06.
,, 14	8 6	Calm; thick. S.S.E.	21 4	5 25 11 30	12 3 21 4	6 0 0 0	10 10 21 2	E.S.E. W.S.W.	21 2	10 4	Light airs and foggy. B. 30·20.
,, 15	9 6	W.S.W. W.N.W.	21 2	0 5 6 30	21 2 12 5	0 30 7 0	21 6 11 10	W.N.W. S.E.	21 6	9 8	Light airs and fine. B. 30·17.
,, 16	10 6	S.S.W.	21 5	1 0 7 40	21 5 12 3	1 40 8 10	21 4 10 0	S.S.W. S.E.	21 4	11 4	Light wind and very fine. B 30·23.
,, 17	11 6	Calm; thick. S.E.	21 9	2 10 8 45	21 9 11 0	2 45 9 15	22 3 10 3	S.E. ,,	22 3	12 0	Light airs and fine. B. 30·27.
,, 18	12 6	S.W. W.N.W.	22 10	3 15 9 35	22 10 10 8	3 35 10 0	23 0 9 6	S.S.E. S.E.	23 0	13 4	Light airs and hot weather. B. 30·25.

1864. Date.	Morning. Moon's Age.	Wind.	Water at Gauge.	Time.	Height.	Afternoon. Time.	Height.	Wind.	Water at Gauge.	Rise and Fall of Tide.	Observations—Barometer.
	days hrs.		ft. in.	hr. min.	ft. in.	hr. min.	ft. in.		ft. in.	ft. in.	
May 19	13 6	S.E.	23 7	4 0	23 7	4 20	23 10	S.E.	23 10	15 7	Light airs and fine.
				10 20	9 6	10 40	8 3	„			B. 30·20.
„ 20	14 6	South.	24 0	4 40	24 0	5 0	24 6	W.N.W.	24 6	16 4	Squally, with showers.
		S.S.W.		11 0	8 0	11 20	8 2	„			B. 30·00.
„ 21	15 6	N. by W.	25 5	5 20	25 5	5 40	25 0	S.S.E.	25 0	17 3	Strong gale and rain.
		N.N.W.		11 40	8 6	12 0	7 9	West.			B. 30·05.
„ 22	16 6	N.W.	25 9	6 0	25 9	0 20	7 10	E.N.E.	25 6	17 8	Strong and squally.
						6 20	25 6	East.			B. 29·95.
„ 23	17 6	W.S.W.	26 2	0 40	7 6	1 0	8 10	N.E.	25 8	18 4	Strong breeze and squally.
		N.W.		6 40	26 2	7 0	25 8	N.N.E.			B. 29·92.
„ 24	18 6	N.N.E.	26 2	1 20	8 0	2 0	6 7	„	25 0	19 7	Fine breeze and cloudy.
		„		7 40	26 2	7 40	25 0	S.S.E.			B. 30·27.
„ 25	19 6	West.	26 6	2 5	7 3	2 30	8 0	N.N.E.	25 10	19 3	Strong breeze and cloudy.
		N.N.W.		8 15	26 6	8 30	25 10	„			B. 29·95.
„ 26	20 6	North.	25 6	2 50	10 0	3 25	7 6	„	24 1	16 7	Strong wind and gloomy.
		N.N.E.		8 50	25 6	9 25	24 1	„			B. 30·05.
„ 27	21 6	N.N.W.	24 8	3 45	9 0	4 15	8 6	N.W.	24 3	15 9	Strong and squally, with rain.
		N.W.		9 45	24 8	10 20	24 3	N.N.W.			B. 30·03.
„ 28	22 6	N.N.W.	24 2	4 45	10 8	5 20	8 8	S.E.	23 0	14 4	Gale and rainy.
		N. by E.		10 45	24 2	11 20	23 0	S.S.W.			B. 29·82.

Copy of Tidal Observations at Grimsby (Royal Dock)—*continued.*

1864. Date.	Morning. Moon's Age.	Wind.	Water at Gauge.	Time.	Height.	Afternoon. Time.	Height.	Wind.	Water at Gauge.	Rise and Fall of Tide.	Observations—Barometer.
	days hrs.		ft. in.	hr. min.	ft. in.	hr. min.	ft. in.		ft. in.	ft. in.	
May 29	23 6	W.S.W. N.N.E.	24 3	5 50 11 50	10 3 24 3	6 15	9 4	N.N.E.	..	14 0	Strong and squally. B. 29·97.
„ 30	24 6	West. W.S.W.	23 4	0 15 7 0	23 4 10 6	1 0 7 30	23 3 8 6	W.S.W. „	23 3	14 9	Fresh and cold. B. 29·90.
„ 31	25 6	N.N.E. N.N.W.	23 3	1 50 8 10	23 3 10 10	2 10 8 30	24 6 9 3	S.S.W. E.S.E.	24 6	15 3	Light wind and fine. B. 29·80.
June 1	26 6	West. „	23 3	2 35 9 10	23 3 9 8	3 10 9 40	24 6 9 0	N.W. „	24 6	15 6	Fine breeze and clear. B. 29·80.
„ 2	27 6	N.E. E.N.E.	24 6	3 40 10 10	24 6 9 0	4 10 10 40	25 0 9 1	E.S.E.	25 0	15 6	Strong breeze and clear. B. 29·86.
„ 3	28 6	S.E. „	24 10	4 40 11 0	24 10 8 3	5 0 11 20	25 3 8 0	S.S.E. „	25 3	17 3	Light wind and cloudy. B. 29·91.
„ 4	New	S.S.E. „	25 2	5 20 11 45	25 2 7 10	5 45 0 0	25 2 8 7	S.S.E. West.	25 2	16 7	Light wind and fine. B. 29·90.
„ 5	1 0	West. W.N.W.	25 3	0 0 6 0	8 7 25 3	0 20 6 25	7 4 25 0	W.S.W. S.W. by S.	25 0	17 8	Light winds. B. 29·85.
„ 6	2 0	W.S.W. W.N.W.	25 8	0 45 6 45	8 6 25 8	1 0 7 0	7 8 25 0	W.N.W. S.S.E.	25 0	17 4	Strong breeze and showery. B. 29·85.

November, 1868.

(Signed) E. H. Clark, C.E., Grimsby Docks.

TIDAL OBSERVATIONS taken at SPURN LIGHTS (Humber Side) and HULL DOCKS, 21st April, 1866.
N.B. The Heights refer to Ordnance Datum.

Time.	Height at Spurn.		Height at Hull.		Remarks.
H. M.	Ft.	In.	Ft.	In.	
A.M.					
4·35	..	..	− 6	6	Wind S.W.
4·45	− 4	7*	− 6	9	* Flood occurred a few minutes before this observation was taken.
4·55	− 4	3	− 6	9	
5·5	− 3	10	− 6	9	
5·15	− 3	6	− 6	6	
5·25	− 3	1	− 6	3	
5·35	− 2	8	− 6	0	
5·45	− 2	3	− 5	8	
5·55	− 1	10	− 5	3	
6·5	− 1	4	− 4	7	
6·15	− 0	10	− 4	3	
6·25	− 0	4	− 3	7	
6·35	+ 0	2	− 3	3	
6·45	0	8	− 2	7	
6·55	1	2	− 1	11	
7·5	1	9	− 1	3	
7·15	2	4	− 0	7	
7·25	2	11	− 0	1	
7·35	3	7	+ 0	7	
7·45	4	1	1	1	
7·55	4	9	1	8	
8·5	5	4	2	4	
8·15	5	10	2	11	
8·25	6	3	3	9	
8·35	6	8	4	4	
8·45	7	1	4	11	
8·55	7	4	5	4	
9·5	7	7	5	10	Wind N.W.
9·15	7	10	6	3	
9·25	7	10	6	10	
9·35	7	11	7	3	
9·45	7	11	7	7	
9·55	7	11	7	10	
10·5	7	10	8	1	
10·15	7	7	8	2	
10·25	7	4	8	3	Wind North.
10·35	7	1	8	4	
10·45	6	10	8	4	
10·55	6	7	8	4	
11·5	6	4	8	0	
11·15	6	0	7	10	Wind East.
11·25	5	7	7	7	
11·35	5	0	7	3	
11·45	4	5	6	11	
11·55	3	10	6	5	
P.M.					
12·5	3	4	6	1	
12·15	2	9	5	9	
12·25	2	3	5	4	

Tidal Observations taken at Spurn Lights and Hull Docks, &c.—*continued.*

Time.	Height at Spurn.		Height at Hull.		Remarks.
H. M.	Ft.	In.	Ft.	In.	
12·35	1	8	4	10	
12·45	1	0	4	4	
12·55	+ 0	4	3	10	Wind N.E.
1·5	− 0	4	3	3	
1·15	− 0	11	2	4	
1·25	− 1	6	2	0	
1·35	− 2	2	1	4	
1·45	− 2	9	1	0	
1·55	− 3	3	+ 0	5	
2·5	− 3	9	− 0	3	
2·15	− 4	3	− 0	10	
2·25	− 4	9	− 1	6	
2·35	− 5	2	− 2	1	Wind S.E.
2·45	− 5	7	− 2	5	
2·55	− 6	0	− 3	1	
3·5	− 6	3	− 3	7	
3·15	− 6	6	− 3	11	
3·25	− 6	9	− 4	4	
3·35	− 6	11	− 4	10	
3·45	− 7	0	− 5	2	Low Water at Spurn.
3·55	..	..	− 5	6	
4·5	..	..	− 6	1	
4·15	..	..	− 6	4	
4·25	..	..	− 6	10	
4·35	..	..	− 7	1	
4·45	..	..	− 7	4	
4·55	..	..	− 7	8	
5·5	..	..	− 7	11	
5·15	..	..	− 8	1	
5·25	..	..	− 8	2	Low Water at Hull.

W. Shelford.

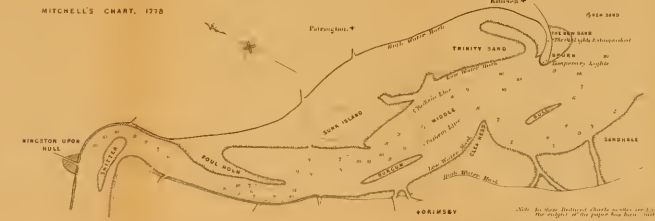
[Mr. Shelford

OUTFALL OF THE RIVER HUMBER.

COLLINS'S CHART. 1684

HEWETT'S CHART. 1828

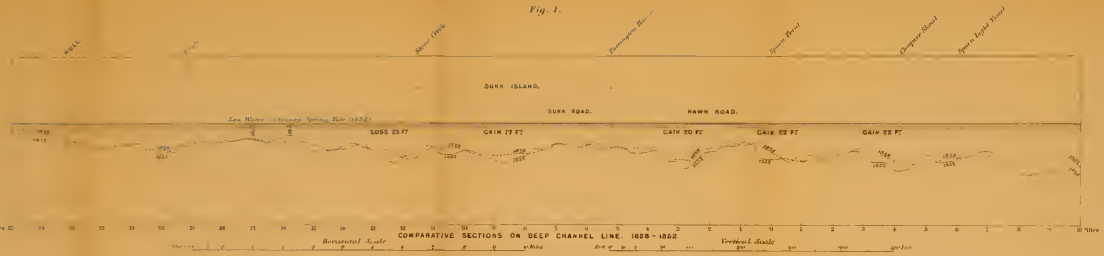
MITCHELL'S CHART. 1778



CALVER'S CHART. 1852.

OUTFALL OF THE RIVER HUMBER.

Fig. 1.



COMPARATIVE SECTIONS ON DEEP CHANNEL LINE. 1828 - 1852

Fig. 2.

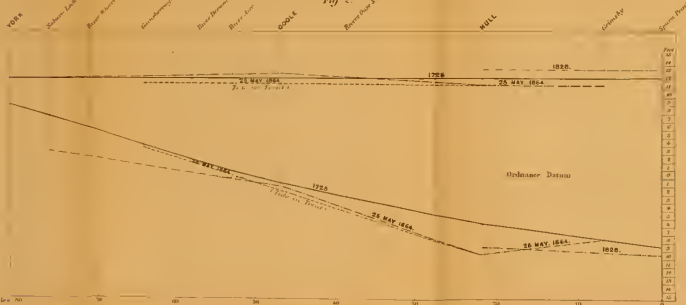
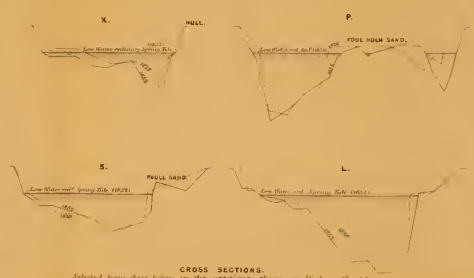
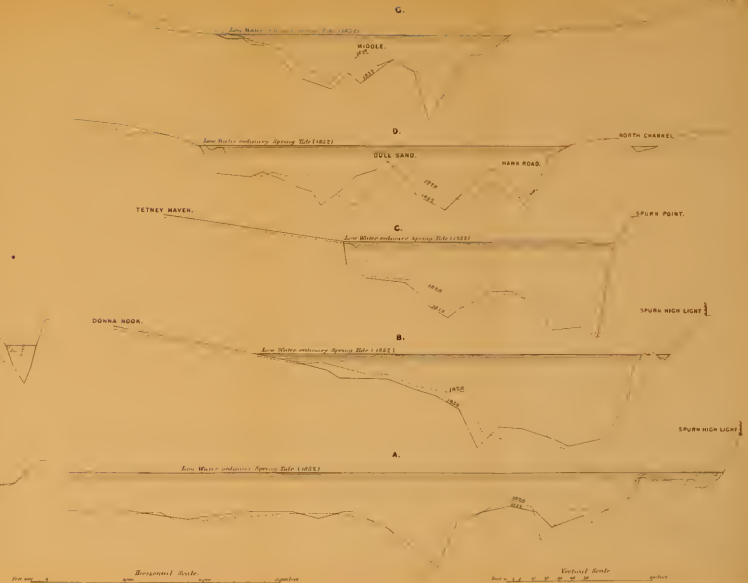


DIAGRAM OF TIDES.



CROSS SECTIONS.

Selected from those taken in the positions shewn on "Colvers Sheet" (See Plate 20.)



Mr. Shelford observed that the diagrams were not copies, but adaptations of the charts. The soundings had been omitted from want of room, and contour lines substituted. Fig. 1, Plate 21, was a longitudinal section, showing the state of the navigation in 1828 and 1852 at dead low water. Plate 21 also contained a selection from a series of cross sections sufficient to indicate the nature of the changes; but it had since occurred to him that the general efficiency of the channel might be shown more readily in another manner. He had, therefore, prepared a supplemental diagram, Fig. 1, p. 494, based upon the hydraulic mean depth, as a test of efficiency. It had been calculated at twenty-two points at high water and low water, with the following result:—

	Feet.
Average hydraulic mean depth in 1828 at low water. . .	21·03
„ „ „ 1852 „ „ . .	21·83
Gain since 1828 . . .	0·80

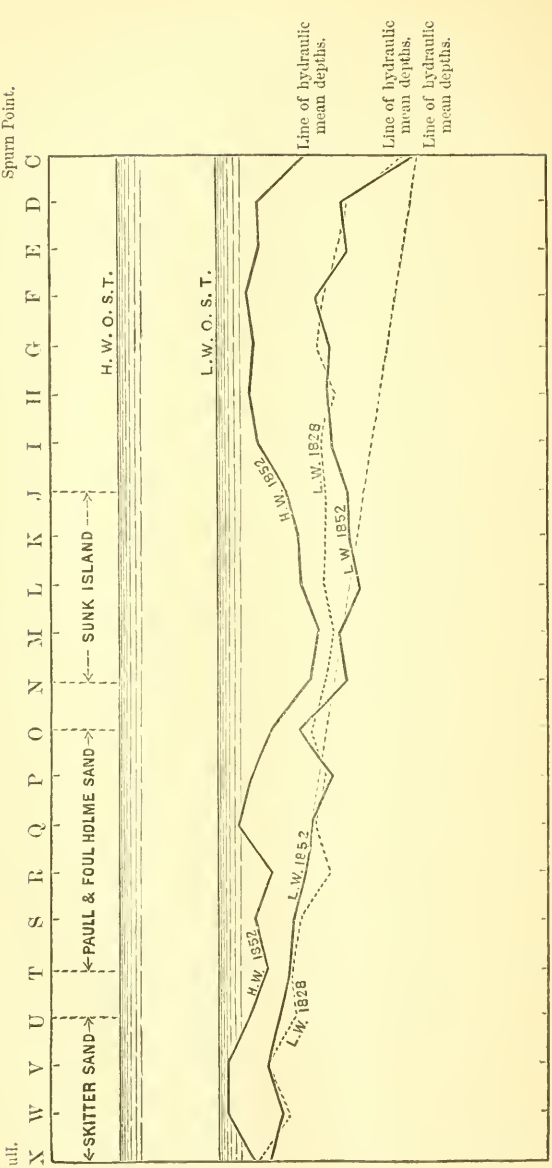
or 3·8 per cent.

The average hydraulic mean depth at high water in 1852 was only 30·81 feet.

This diagram was interesting in other respects, as indicating the greater irregularities of the channel between high and low water than below low water. It might be made also to show the effect of the indents and shoals, by adopting some standard of comparison; as, for instance, by the light dotted line, which joined the hydraulic mean depths calculated at points where the channel was most perfect below low water—such as at Spurn Point, Sunk Island, and Paull Sand. The effect of the indent inside Spurn Point was very plain. Similarly, the effect, not only of the indent, but of the sand at the Spurn, and the Foul Holme and Skitter Sands, might be shown, if a similar line of comparison was applied to the hydraulic mean depths at high water.

Mr. Redman remarked, that the Author had rightly stated that the estuary of the Humber was the embouchure of the largest drainage area of the United Kingdom. The estimate of 10,500 square miles was undoubtedly correct; the relative drainage area of the Severn being 8,000 square miles, and that of the Thames 6,000 square miles. It had its outlet in a range of coast subject to a larger amount of change produced by the action of the sea than any other relative extent of seaboard in the kingdom. From the outcrop of the chalk at Flamborough Head to the Spurn, there was a coast-line of 40 miles; and again from Spurn Point to Hunstanton, where there was an outcrop of the red and white chalk forming Saint Edmund's Point, at the eastern boundary of the Lynn estuary, there was another 50 miles of seaboard. The changes on that line of coast, which, geologically speaking, was all diluvial between these two outcrops of chalk, had been very re-

Fig. 1.


Cross Section, Hull. to Spurn Point.
X W V U T S R Q P O N M L K J I H G F E D C
SKITTER SAND
PAULL & FOUL HOLME SAND
SUNK ISLAND
H. W. O. S. T.
L. W. O. S. T.
H.W. 1852
L.W. 1828
L.W. 1852
H.W. 1828
L.W. 1828
L.W. 1852
Line of hydraulic mean depths.
Line of hydraulic mean depths.
Line of hydraulic mean depths.

markable. Smeaton estimated the annual loss at 10 yards per annum.[1] Certain local writers had also estimated that Hornsea, which was remarkable for its mere, was once 14 miles distant from the sea. That was apparently exaggerated; for the recession of the coast from a straight line from Flamborough Head to Spurn Point was about 7 miles, and the estimate of 14 miles degradation, would produce a curved line of coast double the depth of the present recession, and projecting 7 miles in advance of the Flamborough and Spurn headlands. The more moderate calculation of 10 feet per annum, endorsed by the Admiralty in "The North Sea Pilot," would produce an enormous amount of detritus on that part of the coast. On the assumption that the average height of the cliffs along that 40 miles range of coast was from 30 feet to 40 feet, and the average degradation 10 feet per annum, the amount of detritus affecting the estuary of the Humber would be 3,000,000 tons per annum. The degradation upon the corresponding distance of 50 miles southward of the Humber, on the Lincolnshire coast, was equally remarkable. There the coast was low, and the proportionate waste relatively smaller; and inasmuch as it affected only the estuary of the Lynn Wash, it was not necessary to refer to it more particularly now. This degradation was evidenced by the ruins of Kilnsea Church, N.E. of Spurn Point; also by the site of Owthorne old church, N. of Withernsea, and by the various erections of the lighthouses referred to by the Author. The former site of Angell's lighthouse was now entirely covered by the sea. The low lighthouse had been erected and re-erected on four or five occasions, and now stood to the leeward of the point, whereas, formerly, it stood to the windward; and in the present Admiralty list of lighthouses, there was a note relative to the Spurn Lights, to the effect that they might be suddenly darkened from the continual encroachments of the sea. This subject, he might remark, was not a new one within the walls of the Institution. In addition to a communication by Mr. Oldham,[2] on the reclamation of the slob lands within the promontory of Spurn Headland, which projected $2\frac{3}{4}$ miles from the main, a Paper had been read before the Institution five years ago, on the construction of the Grimsby Docks, and in the course of the discussion allusion was made to the then condition of the Spurn Point. Sir Edward Belcher submitted a proposition[3] in reference to the opening of an artificial channel through the Point. There were certain breaches (the Middle Bents) in the Spurn Point between the mainland and the Spurn, which he did not see indicated on the diagram.

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[1] *Vide* "A Narrative of the Building of the Edystone Lighthouse, &c.," Appendix, p. 188. Fol. Lond., 1813. 2nd edition.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 454.

[3] *Ibid.*, vol. xxiv., p. 54.

Reference was made to the probable effect of a breach in the Point, and the consequent opening up a new channel. At present the depth of channel on the north of the Bull Sand averaged from 40 feet to 50 feet, and on the south side there was a depth of from 50 feet to 60 feet. One peculiarity of the Spurn Point, which was characteristic of all these formations, was the greater depth of water contiguous to the projection of the Point than elsewhere, amounting to 70 feet. This was noticeable at Orfordness, Dungeness, Langley Point, and similar Nesses. The estimate made by the Author of the Paper in reference to the increased range of the tide must be received with caution. The low-water depths given in Collins' and other ancient charts were not referred to any fixed datum, and he thought, for those reasons, that the estimate of 8 feet or 9 feet increased range of tide was somewhat speculative. He had from long experience found great difficulty in drawing certain deductions from comparisons of ancient and modern charts. No doubt by reclaiming Sunk Island and Trinity Sand, and stopping up the North Channel within the Point, an improvement of the outfall would result; and by the erection of groynes on the seaward side much good might be effected, not only by the reclamation of land, and the strengthening of the natural mole formed by the Spurn, but also improving the outfall, by directing and concentrating the effluent waters. The ulterior effect of a breach in the Spurn Point would be the production of three channels in lieu of two, and a probable reduction of 10 feet in the average depth of the three channels as compared with the two.

The Humber had been described by local professional witnesses, in evidence before the Tidal Harbours Commissioners, as one of the finest rivers in the kingdom in natural facilities, in coming up to Hull from Spurn, and it had been held that Liverpool was not to be compared to it, and that had art but assisted Nature, as it might have done, Hull would now have been a far superior port to what it was.[1]

The annual foreign tonnage of Hull was $1\frac{1}{2}$ million, as compared with 6 millions at Liverpool and at London, and $2\frac{1}{2}$ millions at Newcastle.

The origin of Spurn Point, formed of low wind-driven sandhills from 10 feet to 20 feet above high water, was apparent, and, notwithstanding local variations of site—the southern and western movement having corresponded with the N.E. degradation of the coast—its origin was remote, and its outline similar to Calshot Point to windward of Southampton Water, Hurst Point to windward of the Solent—all of which in their general conformation, as at present, were found in the earliest plans. At Holkham, on the

[1] *Vide* "Tidal Harbours Commission. Second Report." App. B., p. 411. Evid. 22 Oct., 1845.

Norfolk shore, a Danish camp just within the seaboard range of sand dunes was evidence of their high antiquity.

There was at the mouth of the Humber, also, the characteristic low shore to the leeward and southward, the Sand Haile. The great range of tide, 19 feet at springs and 11 at feet neaps, and the great low-water depth of 50 feet, made this one of the most important natural harbours on the East coast.

Mr. Abernethy said the Paper was chiefly historical, and treated briefly on the causes of the changes that had taken place in the navigable channel of the river. The subject had been previously debated elsewhere, and he thought the principles then enunciated, in support of a scheme for reclamation between Spurn Point and Sunk Island, were borne out by the different changes and various facts now mentioned.

In the first place, as to the cause of the changes which had taken place:—it would be observed in Collins' chart of 1684, that a channel surrounded Sunk Island. During the flood, at the point called Stanningborough Flats, the tide was deflected northward, and a considerable stream passed up the channel between Cherrycum Sand and Sunk Island; but between Patrington and Sunk Island the current ceased, and the channel silted up. In 1778, a sand-bank had formed round Sunk Island; but the effect of the flood-tide there was still to impinge northward, so as to form the shoal shown at that point. The Foul Holme Sand no doubt gradually projected further seaward, and eventually joined the low-water foreshore of Sunk Island. That was shown very clearly by Hewett's chart of 1828. Subsequently, when Sunk Island was connected with the mainland by reclamation, the tide passing round Spurn Point was deflected by the outline of the shore to the southwards towards Burcom Sand, and on the ebb south of the Bull Sand, and thence suddenly to the northward. A comparison of Hewett's chart of 1828, with that of 1852, showed that there had been no material alteration in Trinity Sand, Sunk Island, and the Bull Sand; but in the interval it would be observed that Sand Haile Flats had receded, and projected less beyond the foreshore, through the deflection of the ebb tide northward. He believed these irregularities were mainly caused by the indent between the Humber and Spurn Point. No doubt if Sunk Island were connected with Spurn Point, and the indent removed, the tide would flow more directly up the channel. The existence of such an indent would always cause irregularities. It had been urged, in opposition to the scheme for filling up the indent, and forming a parallel shore to guide the flood and ebb tides, that the volume of tidal water, which served to keep down the shoals seaward, would be lessened. On that point he thought the result of operations in the Tyne was a sufficient answer. There parallel shores had been formed, and

the banks caused by the indents removed by dredging; and the tidal ebb and flow, guided by the parallel shores, had kept the navigation open and clear, and the Bar was in great part removed. The same principle should be followed in the Humber as in the Tyne; indents should be filled, and the embouchure embanked between Spurn Point and Sunk Island by parallel shores; and the shoals caused by indents, where the ebb currents were not sufficiently powerful to act upon them, should be removed by dredging. He laid down these general principles as the best mode of improving navigable rivers of this character.

Mr. Bateman observed that, of the original estuary of the Humber, the water space covered by high spring tides was 400 square miles, which had been reduced to 110 square miles by reclamation: still the river maintained its depth, and improved its channels, though so large a volume of tidal water had been excluded. This confirmed the view that tidal water might, under certain conditions, be excluded, and the rivers be improved at the same time. It was seen every day in other rivers. The Mersey was an instance of the improvements effected by straightening the channels and rectifying the currents. A useful and valuable point in the Paper under discussion was the information given as to the effects which these successive reclamations had produced upon the channel of the Humber. Spurn Point no doubt acted an important part in more ways than one:—first, as a breakwater; and then as a groyne, narrowing the channel at the entrance of the Humber, making a deep at its point, and so preventing the dispersion of the flowing or ebbing tide to the extent which would obtain if that point did not exist. Immediately above Spurn Point occurred a large expansion in the neck of the bottle, which diminished the momentum of the water flowing up the estuary. If that were enclosed from Sunk Island to Spurn Point, a straighter current would be given—the sand would be removed, and the river deepened. But Spurn Point answered another useful purpose. It afforded shelter to a deep channel for small vessels, kept open by an eddy or rotatory action, which, though it retarded the current of water upwards, produced and kept that channel open in a nearly constant condition, and thus maintained a safety harbour, which was much wanted on that coast. This was so important that it was matter for grave consideration, whether the advantages afforded by that harbour should be thrown away for the sake of reclaiming the land, or improving the main channel. The increase in the capacity of the estuary between 1828 and 1852 was in some parts as much as 33 per cent.: during that time there had been no engineering works or material alteration on the shores to account for it, nor any important reclamation of land which would so affect the current

as to create such an enlargement of the channel; and the cause had still to be sought for. In the estuary of the Mersey, although the narrow "neck of the bottle," as it was called, had been encroached upon by the Liverpool and Birkenhead Docks and the Wallasey Pool Enclosure, which excluded a considerable quantity of tidal water, the straighter run of the tide and the greater velocity of the current had increased the estuary above Liverpool about 10 per cent. in the thirty five years between 1822 and 1857. How far that was still going on he did not know, but he had reason to believe that the capacity of the estuary above Liverpool was still increasing, and would continue to do so as long as the walls at Liverpool and Birkenhead were judiciously continued, and the cross currents, which formerly existed, destroyed or prevented.

He was not long since at Spurn Point, where Mr. Coode had constructed groynes, to arrest the shingle as it passed southwards, and to protect the Point from the destruction which seemed to threaten it. The Author of the Paper seemed to think that, if that course was continued, and an accretion of material took place, there would be danger of the sea making a breach to the northward. On that point there would be difference of opinion. No doubt groynes constructed at right-angles to the shore would arrest the shingle; but to make such works effective, it was desirable that they should not be confined to Spurn Point, but be continued up the coast for a sufficient distance to cover the whole of the promontory, and secure it from the destructive action of the sea, or it might be outflanked, as suggested by the Author. Groynes were an effectual means of arresting the progress of shingle, and obtaining an accumulation of that material, and he believed those adopted by Mr. Coode had been so far successful.

Captain Calver, R.N., remarked, that the Humber was one of the most important rivers on the English coast; and in treating that river for improvements, it was necessary that the utmost caution should be observed. Some rivers were only of importance to the localities in which they existed; but the Humber, having a deep-sea entrance, was a harbour of refuge for the east coast: fleets had taken refuge there, and it had often been the means of saving life and property. He would not dwell upon the movements of the currents or the little changes of the foreshore. As far as he gathered from the Paper, the conclusions of the Author were, that, as the basin of the Humber had been restricted by embankments, the navigable channel had been improved. But an inspection of the charts went rather against the Author's theory; for, though the deep channel of Collins' time might not have been so deep as it was now, there was a greater breadth of navigable channel in his day. The arguments in favour of excluding tidal water were various. It was said, if the water which flowed over

this estuary was excluded, the same amount of water would be thrown into the upper portion of the river; but there was nothing in the movement of the tidal stream to warrant such a view. The tide, in filling the river, sent off oblique streams to the wide indent between Sunk Island and Spurn Point without the slightest disturbance of the main current. There was nothing in that movement to warrant the idea of retardation or friction. Experience was also an important consideration in cases like this. It was well to see whether, in great enclosures, a corresponding elevation of the level in the upper parts of the river had been observed. In the Thames, which was extensively embanked, there had been no elevation of the water level. At Lynn, within a recent period, the whole of the navigation below the town had been altered; but the high-water level was not so high as it was before the river had been treated. In the Dee, two-thirds of the estuary had been cut off, but no impression was made upon the high-water line. In the Clyde, the most extensive restrictions had been adopted, but they had had no effect upon the high-water level. At the Blythe, in Suffolk, an extent of 2,000 acres, formerly covered by the tidal flow, had been reduced to 450 acres; but the tide flowed only to its former level: and in the Tyne 100 acres had been cut off up to the time of his survey in 1849, yet it made not the slightest impression upon the high-water level; and, though considerable dredging had taken place since, still the high-water level had not been affected. In a case like this, where the river formed an important harbour, two considerations must never be separated; viz., the condition of the internal channel, and the navigation at the mouth of the river. Charts of the more modern surveys showed the mouth of the river encumbered by sands, which did not formerly exist, and they afforded good proof that, while the depth of the channel might have been increased, the quantity of tidal water had been materially lessened. It was possible to reduce the breadth of the river by embankments till the section at the mouth would be little more than at the confluence of the Ouze and the Trent. At the present moment the section of those rivers was 13,000 square feet at low water, and at the mouth of the Humber it was 680,000 square feet; but if the river were materially reduced, and the tidal capacity lessened, the entrance might be prejudicially affected. The Tyne could not be adduced in illustration, because it was a narrow river: and whatever mistakes were made by restrictions were remedied by dredging. The condition of the Tyne did not depend upon lateral restrictions, for the Commissioners improved it by dredging; and probably more tons of sand were taken out of the river than of coals from the mines. In rivers of restricted breadth there was the available process of dredging; but in a channel several miles wide, a mistake once

made would be without remedy. With regard to Captain Hewett's levels, he could find no clue for the datum, nor whether it was conveyed through the whole river: therefore any comparison between Captain Hewett's labours and his own failed to have value. But he believed no change had taken place in the régime of the river to occasion such a difference in comparatively recent times, between the tide level at sea and at Hull, as had been adverted to in the Paper; for he found, in rivers with a wide mouth in comparison with the basin to be filled, the highest level was at the higher part of the river. He would merely observe further, in general terms, that there might be circumstances where the public interests called for a slight reduction of tidal area, provided the object to be served warranted an inroad upon a broad principle; but, generally speaking, it was a safe and sound doctrine, founded on experience, that the tidal volume should be preserved, and its efforts restricted. The Humber came within that category, more particularly as the condition at its mouth affected, to a considerable extent, the safety of the life and property employed in the commerce of the eastern coast of the country.

Mr. Coode had been professionally connected with the defences of Sunk Island for ten years, and in charge of the Spurn Point for the last six years. The few remarks he had to offer would be, as nearly as possible, in geographical order.

A question had been raised as to the expediency of constructing groynes to the eastward of Spurn Point. Certain groynes had been erected on the eastern face of Spurn Point; and it was suggested that those groynes should be carried along the coast to the north-east. There were two reasons why that should not be done: first, if the landowners would not take care of their own property, it ought not to be done with the public money. A second and still stronger reason was this: it might not be generally known that the inhabitants of this district took, he might almost say, every particle of shingle they could catch. He had seen them even raking out the tide pools on the beach to get the shingle; and it was admitted that 60,000 tons of shingle per annum were carried by rail or water from the south-east part of the Holderness coast, in order to make and maintain the roads in Yorkshire. If the groynes were carried out along the coast on the north-east of Spurn Point, he had no hesitation in saying that not 10 per cent. of the quantity of shingle that now reached Spurn would get there, and which—small as that quantity was—contributed largely to the maintenance of Spurn Point. He had not shut his eyes to the risk of this Point being outflanked. The groynes had collected a large quantity of material all along the Point, particularly at the north-east end, and they were not at present in danger of being outflanked at this particular point. If by any means people could be prevented from

taking the shingle away, it would be a great boon to the frontagers in this district.

The maintenance of Spurn Point came under his charge in the year 1863, on the death of Mr. Walker, Past President, Inst. C.E., who had stopped a large breach which was made at the middle of the Point in December, 1849, by means of a chalk bank at a cost of about £25,000. Captain Vetch reported upon this breach at the time it occurred, and recommended the construction of groynes on the eastern face of Spurn Point. Mr. Walker agreed with Captain Vetch, that the right method of protecting Spurn Point, and of closing that breach in particular, was by groynes. For some unexplained reason, however, Mr. Walker never constructed a single groyne there, but resorted to the chalk bank, by means of which the breach was stopped at great cost. This had left behind an evil which remained to this day, and other measures would have to be adopted with regard to that particular part of the Spurn; not because Spurn Point was unprotected on the sea face, but because the chalk bank projected into the Humber about the middle of the Spurn, and acted in the same manner as a groyne, by stopping the shingle and sand which passed round Spurn Point, and travelling to the northward along the Humber side of the Spurn, and stopped by this chalk bank; the foreshore to the northward was consequently weakened on the Humber side. Captain Vetch, in addition to groynes on the eastern side of Spurn Point, recommended that a large portion of this indent should be enclosed, with a view to the protection of Spurn Point. He thought Captain Vetch did not obtain the whole of the facts, as he had evidence that the causes which operated to produce the great breach did not come from the Humber side, but from the sea side. During north-west gales, in December 1849, there was a very high tide in the North Sea; and the tide flowing over the Spurn, (which was very low at this part,) caused the breach.

The next point he would direct attention to was the condition of the tides at the Humber entrance. The first and main part of the flood-tide coming down the North Sea struck the south shore near Clee Ness, passed across between the Bull Sand and the Middle Sand, and then set up the Humber. An after-tide came close round Spurn Point, and then passed up the Humber. The flood tide which came in on the south shore ran, at the rate of $2\frac{3}{4}$ knots per hour, up towards the north-west, and passed the Middle Sand at the rate of $3\frac{3}{4}$ knots per hour; while the tide which flowed close round Spurn Point travelled at the rate of only $1\frac{3}{4}$ knot per hour.

With regard to the policy of enclosing the indent and excluding the tidal water, it was proved beyond doubt that the proportion of tidal water excluded would be only about 2 per cent. of the whole

quantity. As far as that went, he did not think it was a matter which would be disadvantageous to the Humber. The conditions as regarded the tidal currents were of far greater moment; and if any considerable amount of tidal current had flowed into this indent, then the enclosure of it might so influence the tidal stream going up the Humber as to improve the river above. Although some of the observations recorded in Calver's chart, Plate 20, were said to have been taken from a chart he had made, and the line of the shore was represented, yet a second line was omitted, which was intended to show that at three-quarters flood the water within that line was perfectly slack, or 'dead.' That line trended towards the shore till it came to the line marked *a*, *a*, on the chart, and at the time of high water it was dead slack over the whole area between it and the shore. Now, if the water was dead slack within that line, which was the limit of the proposed enclosure, he did not see how the formation of a bank could so affect the currents flowing up the Humber, as to have any material effect upon them, one way or the other. He could well understand, and would be ready to admit, that if there had been a strong current setting from the main flood stream into this indent, the formation of an embankment might have so deflected and directed the current as to improve the condition of the Humber above; but as that was not the case, he did not think it could be beneficial in any way. As to the statement that the condition of the river had improved of late years, he considered, without going into any questions of cause and effect, that the charts of Hewett and Calver showed the contrary, because between Hull and the Foul Holmes Sands, where there was a depth of water of 5 fathoms, according to Hewett, there was now a shoaling amounting to a bar, and the whole condition of that part of the Humber seemed to have deteriorated.

Returning to the subject of Spurn Point, although the groynes had been successful, yet there was never any idea on his part, as intimated in the Paper, of converting the westward, or retiring movement of the Spurn, into an eastern or advancing movement. The object was essentially conservative; and if he could prevent the sea making inroads upon the Spurn, or driving the Point westward, that was all he hoped to gain. He had found of late that, in addition to the groynes, it was better in similar cases to rely as much as possible, upon the advantages that might be derived from the use of mat-grass in strengthening sand-banks, and enabling them to resist the inroads of the sea. Within the last eighteen months he had, in several weak points along the Spurn neck, made small embankments 1½ yard or 2 yards wide at the top, with slopes of 4 to 1, protecting them at the sea foot by stakes and wattles, and covering the tops and sea faces with sea-mat or mat-grass, *Arundo arenaria*, commonly called bent grass. The

growth and effect of that plant had been very satisfactory. These banks were seldom more than 6 feet or 7 feet in height, and the crest was 3 feet or 4 feet above high-water spring tides. On the occurrence of a high tide, on the 1st of March, 1869, the sea would doubtless have made a breach through the Spurn, but for one of these embankments which had been completed in the previous November. This system could be safely recommended in similar cases; he advised the levelling of abrupt knolls to flat easy lines, the trimming down to gentle slopes of all vertical faces, and that the surfaces should be covered with bent grass, which had extraordinary power in strengthening sea embankments. The protection afforded by this grass was held to be of so much moment three hundred years ago, that by an Act of Parliament in the reign of Elizabeth it was a penal offence to cut it down; and in the reign of George II., another Act was passed on the same subject. For the first offence the penalty was 20s. or three months' imprisonment; and for the second offence the punishment was twelve months' imprisonment, with hard labour. A penalty of 20s., or three months' imprisonment with hard labour, was also imposed for being found in possession of this bent grass within 5 miles of the sand-hills. In Scotland the regulations were still more stringent; and it was a penal offence to be found in possession of it within a distance of 8 miles from the shore. From his experience of the utility of this plant, he thought this was a wise piece of legislation, as it had saved the expenditure of thousands of pounds at the Spurn within the last few years.[1]

Mr. Murray stated that at Flamborough Head, at the full and change of the moon, it was high water at half-past four o'clock, with a tidal range of 18 feet. A branch passed suddenly round the Point to the westward, and swept Bridlington Bay and the low coast of Holderness, which had for a long course of years been wasting away. Another branch of the flood proceeded more directly southward for the mouth of the Humber; and the separation of these currents produced the great Smithwick Bank. The bed of the sea between Flamborough Head and the Dogger Bank was here reduced to 30 fathoms in depth.

It was high water at the Spurn Point on full and change at 5h. 20 mins. attaining a range of 18 feet 9 inches, but the main stream took a more southerly direction; and as the bed of the sea opposite the mouth of the Humber was reduced to 15 fathoms

[1] Captain Cator, R.N., the Acting Conservator of the River Humber, in his annual report for the year ending 1868 to the Board of Trade, states, that "the accumulation of sand and gravel along the whole sea face of the Spurn is almost incredible, when the slight means of obtaining such results are taken into consideration."

in depth, and southward of that contour line by extensive shoals lying off the coast of Norfolk, the stream of flood was forced forward, scooping out in its course a channel called the Inner Silver Pit. Thence it ran into Lynn Deeps, where on full and change of the moon it was high water at 6 o'clock, with a range of tide of 23 feet.

The stream of flood in its southerly course threw off a branch into the Humber, scooping out a long narrow pit of deep water, terminating opposite Spurn Point. The depth seaward of this tract of water was 17 fathoms, reduced at its western extremity to 12 fathoms. The flood penetrated the Humber south of the Bull Sand, and proceeded onwards to Hull.

The main stream of ebb ran outward to the north of the Bull Sand and close to Spurn Point, after passing which it had a tendency to run northward, but, being checked with the later flood-tide running southwards along the coast of Holderness, deposited matter in suspension, and caused the extensive shoals to the eastward of Spurn Point. By a comparison of the charts of 1828 and 1852, these shoals appeared to have increased; but the deep water southward of Spurn Point had become enlarged and deepened.

The valuable anchorage of Hawk Roads had maintained itself, and in places was deeper, there being now a depth of from 8 to 12 fathoms of water. The Bull Sand had become enlarged; and, in consequence of the projecting foreshore of Grimsby Docks, the Burcom Sand opposite had been forced considerably more to the northward. The Inner and Grimsby Roads existed as heretofore, and the flood channel between Clee Ness and the Bull Sand was deeper. The 5-fathom contour line of the Sand Haile Flats had extended itself to the northward, but not to any great extent.

If the extensive bay within Spurn Point, which was dry at low water, comprising the Sunk and Trinity Sands, were partially embanked, so as to lessen the receptacle for tidal water, no injury, in his opinion, would accrue to the flow up the Humber; on the contrary, it would have a tendency to cause the tide to rise higher upwards, and the increased body of water, on its return on the ebb, would have a beneficial scouring effect downwards on the channels.

By enclosing a great part of the foreshore of the Mersey, for the formation of the extensive range of docks at Liverpool, giving thereby a fairer direction to the stream, the flood tide had been made to flow more freely up the Mersey. Accurate levels were taken under the direction of the late Mr. Rendel, and observations had been made during a spring and neap tide in 1844. The following was the result:—

Spring tide, June 3rd, 1844.

	Time. h. m.	Height. Ft. In.
At Formby Point	12 15 p.m.	23 4
„ New Brighton	12 30 „	23 2
„ Prince's Basin	12 50 „	23 7
„ Ellesmere Port	1 10 „	24 7
„ Runcorn	1 25 „	25 4
„ Fiddler's Ferry	1 50 „	25 2
„ Warrington Bridge . . .	2 30 „	25 8

Neap tide, June 10th, 1844.

„ Formby Point	6 45 „	17 9
„ New Brighton	7 5 „	17 8
„ Prince's Basin	7 10 „	18 1
„ Ellesmere Port	7 35 „	18 6
„ Runcorn	8 5 „	19 0
„ Fiddler's Ferry	8 50 „	18 10
„ Warrington Bridge . . .	9 45 „	18 9

In his opinion—and he believed the majority of engineers coincided in the views entertained by Mr. Rendel—the building of the river wall across the mouth of Wallasey Pool, nearly parallel with the river wall of the Liverpool Docks, would cause a greater influx of flood-water, notwithstanding the enclosure of Wallasey Pool and its embankments, amounting to 340 acres, which on its reflux would prove beneficial to the channel of the river.

He should like to be informed what had been done to protect the seaward frontage of Spurn Point. Considering the deposits that were daily taking place to the eastward of Spurn, it would be well to take advantage of them, and to run out in an easterly direction a substantial groyne from the lighthouse, as far as the Middle Bank, extending it seaward hereafter if necessary, for the purpose of directing the current of ebb, and guiding at the same time that of the flood into the river; the detritus collected on its northern side would protect, in a permanent manner, the narrow neck of land between the main and Spurn Point.

Mr. J. T. Harrison could not admit that the works hitherto executed within the Humber had improved the tidal action. At one point below Hull there was a diminution in the depth of water from 27 feet at low water to 22 feet. Many ships bound for Hull drew 24 feet of water. In 1828 there was sufficient depth of water for such vessels at low water, but that was not the case now. Besides, the Author had shown that outside the Humber, banks, which might be called the bar, had accumulated 20 feet between 1828 and 1864, thus indicating a deterioration of the harbour. The longitudinal section of the Humber also showed that the alternations of deeps and shoals between the entrance and Hull had increased in degree from 1828 to 1852. The hydraulic mean depth at low water in 1828 was a tolerably regular line, but in 1852 it was very irregular. He agreed with the Author

that no works of a character to produce such decided effects had been carried out on this section between 1828 and 1864; and the works were generally designed to give regularity to the channel of the river. He thought the enclosure of any space within the Humber, that would lead to the acquisition of land for agricultural purposes, would not be mischievous to the river. The warping up of the land was due to a natural process, and would increase in a few years; therefore he thought a large portion of the space within the Spurn might now with advantage be reclaimed. He was confident if an attempt were made at reclamation beyond a certain point, the river would assert its right and wash down the wall intended to enclose the land. The causes influencing the condition of the Humber lay outside the harbour, not within it. The Author had drawn attention to the fact that the sea encroached upon the coast between Bridlington and Spurn Point at the rate of $2\frac{1}{4}$ yards per annum, and removed 3,000,000 cubic yards of material. That degradation of coast, in a length of 30 miles or 40 miles, represented a loss of 24 acres per annum, which, at £50 per acre, amounted to £1,200 a year. Such an encroachment of the sea between Bridlington and Spurn Point was worth consideration. The cliffs consisted of diluvial boulder-clay, which supplied the mud and fine sand that formed the shoals in the Humber, and the mud was deposited by warping. On the other hand the boulders produced the shingle which was carried along by the waves, and formed the Spurn Point. This degradation also supplied vast masses of sand, which, conveyed by the current into the mouth of the harbour, formed, with the mud, the sand-bank at the entrance. Now the waves acting upon the coast, and undermining it, and the tidal currents, were the influences which effected these changes. The tidal wave from the north met with no decided opposition till it reached Flamborough Head. He might mention that the time of high water at Aberdeen and at Flamborough Head differed only $3\frac{1}{4}$ hours; but between Flamborough Head and Spurn Point the difference was $1\frac{1}{4}$ hour: though the distance between the former points was six times as great as between the latter. This showed that the wave travelled through the deep water with great rapidity, and that there was nothing to interfere with it till it met the projecting coast at Flamborough Head. The height to which spring tides rose between Aberdeen and Flamborough Head was from 16 feet to 18 feet; but from Flamborough Head southwards to the Wash it was from 20 feet to 23 feet, in consequence of the check the tide received when it reached this point and the projection of the Norfolk coast. The tidal current between Flamborough Head and the Spurn caused a uniform depth of 30 feet at low water within 1,000 yards of the shore. Flamborough Head and

the Norfolk coast consisted of chalk, which was not easily encroached upon by the sea; but the boulder-clay between Spurn Point and Bridlington, and the alluvial deposit on the Lincolnshire coast, were readily eroded. Thus the tidal wave, setting into the bay, tended to fill up the Humber and the Wash, and to form a deep bay similar to the Great West Bay on the southern coast of England. He would next draw attention to the formation of the spit at the Spurn. It appeared that its length was 4,400 yards from the mainland to Spurn Point: of this 2,643 yards were formed between the years 1676 and 1864—a period of less than two hundred years. In the first ninety years it had elongated at the rate of 20 yards per annum; during the next five years at the rate of 56 yards per annum; in the ensuing fifteen years 10 yards per annum; in the sixty-five years down to 1851 only at the rate of 4·6 yards per annum; and from 1851 to 1864 it had progressed southward at the rate of 8·7 yards per annum. It had moved also inwards, as shown by observations at the lighthouses, since 1771. The sea gradually destroyed the foundations of the small lighthouses and drove them from the eastward to the westward of the great lighthouse. Between 1771 and 1816 the movement was at the rate of $2\frac{2}{3}$ yards per annum, between 1816 and 1830 of 5 yards per annum, and between 1834 and 1864 it was 6 yards per annum. This showed a rapid increase of late years in Spurn Point, both southward and westward, towards the Humber; and it diminished the width of the river at the entrance. This contraction of the entrance gave rise to an encroachment upon the opposite coast, and increased the velocity of the tide opposite the Point, whereby the depth was largely increased, and a better tip afforded for the material carried along the coast, which hastened encroachment. In this way the Bull Sand on the inside, and the height of the bar on the outside, had been increased; and, generally, sand had accumulated eastward of Spurn Point; while the formation of a succession of deeps and shoals all the way up the river had decidedly injured the navigation.

To remedy these evils he approved of the plan, already advocated by Mr. Murray, that a pier, not a groyne merely, should be run outwards from the point where the spit joined the mainland, towards the Spurn light-vessel. The pier would cause the beach to collect on the north side, and would prevent the shingle drifting to the entrance of the harbour, from which point it was now washed inwards and outwards, forming sand-banks, and it would enable the tidal waters to remove the banks more readily.

Mr. W. H. Bartholomew remarked, that the Paper was limited to the outfall of the Humber, while his attention had been principally, though not exclusively, directed to the river above Hull.

From his knowledge of the Humber, he had some doubts if the river had been improved as the reclamations advanced. It might have been otherwise if the reclamations had taken a better form, so that their frontage lines had conformed to the proper curves for guiding the tide up, and directing the currents down the river through the same channels. With regard to the statement that the tide at Hull rose higher than formerly, he took exception to that, so far as regarded Goole, where there had been no advance, except occasionally in the case of over-blown tides. These arose from the waters of the Atlantic being driven by continuous strong north-west gales into the North Sea. So far as Goole was concerned, the tidal register did not record any permanent advance in the height of the tides.

Mr. Parkes said, that Captain Calver had raised an interesting question, to which Mr. Murray had also alluded—the effect produced upon the propagation of the tide up any river by changes in the condition of the channel. Captain Calver had mentioned instances in which no material change had been effected in the flow of the tide, or in the height to which it rose in the upper part of the river, notwithstanding that great changes had been made in the channels. His own investigations confirmed Captain Calver's conclusions. Persons were apt to exaggerate the effect that might be produced by artificial works in this respect. Captain Calver mentioned the case of the Tyne, where great works had been carried out, but the tide did not rise higher than formerly; and he believed the effect of the works of river improvement in the Clyde had been to raise the level of high water only about 1 foot, notwithstanding that those works had produced so extraordinary an effect in introducing an increased volume of tidal water. He believed that in the rivers on the east coast—the Ouze, the Nene, the Welland, and others, where much had been done to lower the bed, and with it the low-water level, little or nothing had been done to raise the high-water level. The case of the river Thames was remarkable. It was well known how great an effect the removal of old London Bridge had on the régime of the river Thames; but he believed the effect below bridge was not very great upon the high-water line. Immediately above the site of London Bridge the high-water line was raised, but at Teddington it was lowered, the low-water level having been depressed by the removal of the bridge, to such an extent as to deteriorate the capacity of the channel for the propagation of the tidal wave. Since the removal of old London Bridge, however, a change had taken place in the tide below bridge. Captain Burdwood, of the Admiralty, had found by a comparison of the tidal observations of 1843 with those of 1867, that there had been an increase of tidal range at springs of 14 inches; the high water being 7 inches higher, and the low water 7 inches lower. That

could only be attributed to the extensive dredging operations. The cases he had mentioned were undoubtedly confirmatory of the theory that an increased capacity, and greater uniformity of channel, were favourable to the tidal flow; but he thought they proved at the same time that the effect was not so great as was sometimes supposed. He had mentioned some instances in which great changes had been made in the condition of the channels without producing any appreciable effect on the tidal flow. He would add one, within his own knowledge, where the tidal channel had been severely dealt with, without any effect being produced upon the flow of the tide. That was the harbour of Kurrachee. It was situated at the head of a bay, about 2 miles within the general line of the shore. This bay was open to the sea at high water, when the shoals were covered; but at low water a half-tide sand-bank confined the channel to one side of the bay. The work to which he had alluded was a groyne 2 miles long, which confined the high-water channel to the same line as the low-water channel, thus converting the approach for the tide from an open bay to a channel 2 miles long, and 2,000 to 3,000 feet wide. It had been predicted that this would prevent the tide rising so high in the harbour. Careful observations were taken before the work was commenced, and it was found that the range of the tide was about 3 inches greater at the head of the bay than at a station close to the open sea. Similar observations after the work was finished showed that, in spite of the changed conditions under which the tidal wave was propagated into the harbour, there was no appreciable change in the comparative range of tide at the two stations.

The Author of the Paper had referred to a series of observations on the Humber, made by a Committee of the British Association in 1864. Mr. Parkes had been struck with their value at the time of their publication, and had examined them in some detail. The results he had obtained affected the question under consideration in this way, that the difference between the level of spring and neap tides was, to some extent, analogous to the difference between an improved and an unimproved channel. If it were proposed to deepen a channel about 6 feet, some of the same modifications might be anticipated in the tidal flow, as would be shown between the flow of spring and neap tides. The observations to which he referred were made simultaneously at Hull, Goole, Naburn, and Gainsborough, from the 9th of May to the 4th of June, 1864, thus extending over a whole lunation, embracing fifty-four complete tides, two sets of springs, and two of neaps.

The accompanying Table A was compiled from these records, and the tides were grouped according to their heights at Hull, so as to exhibit the different effects upon the tidal flow, as the channel was

more or less full, and the tidal currents more or less strong. It would be seen, on comparing the heights at Hull with those at Goole, that while the average elevation of the lowest group of tides was 9·4 inches, that of the highest was 17·2 inches, and the intermediate ones presented a continuous gradation of increase. Again, if the times of high water were compared, it would be seen that, while the lowest group required 1 h. 44 min. for the propagation of the crest of the wave from Hull to Goole, the highest group required only 1 h. 15 min., and the gradation of decrease was continuous in the intermediate groups. If, however, the comparison was made between Hull and Naburn, or Gainsborough, this regularity would not be found in the heights. At these stations the relative levels of high water were affected by circumstances which did not exist, to the same extent, at Goole. One of the most important was the quantity of fresh in the river. An examination of the details of the Table would show that, with a moderate amount of fresh, the tide had nearly the same range whatever the low-water level might be, and thus the elevation of high water above its level at Hull would depend less on the height of the tidal wave than on the state of the fresh-water stream. The rate of propagation, however, was little affected by freshes in the river; but the greater the tidal wave at sea the more rapid the propagation. Again, it would be observed that the height at Naburn and at Gainsborough was frequently less than at Goole, especially at high tides, and when there was little fresh. This showed that while the conditions of the lower parts of the rivers were favourable to an increase of tidal range, those of the upper parts were unfavourable.

All these facts indicated the extreme complication of the causes which affected tidal flow in a river, and that the extent to which tidal flow might be affected by changed conditions was not great in comparison with those changes themselves, for the difference between the elevation of a spring and a neap tide, under such favourable circumstances as were found between Hull and Goole, was only about 8 inches.

Table B exhibited a comparison between the tides at Hull and at Grimsby for the same period. The Hull records were those of the Committee of the British Association; those of Grimsby were taken from the Paper under discussion. He would first call attention to the fact that, by the Ordnance levels, the mean-tide mark was 13 inches lower at Hull than at Grimsby. On endeavouring to trace the cause of this apparent discrepancy, he found that the authorities of the Ordnance Survey had published various apparent anomalies of a similar character; for instance, the mean-tide mark at Birkenhead was 13 inches higher than at Liverpool. At Fleetwood it was 2 feet higher than at Silloth, and other cases were equally

incredible. He had no doubt that more careful observations would show the erroneous character of these results, and he therefore considered himself justified, in spite of the Ordnance levels, in assuming that the half-tide marks at Hull and Grimsby were practically in the same horizontal plane, or if there were a difference, that Hull was higher and not lower than Grimsby. In Table B, he had assumed that the mean of all the high and low waters, at each port respectively, would represent the same level, and as the assumption gave a difference of 17 inches between the zeros of the gauges, he had deducted that amount from all the Grimsby heights, so as to refer them to the zero at Hull. He would now call attention to the details of the Table. The tides were grouped in the same way as in Table A. It would be seen that the high water of the smaller tides was elevated 8·7 inches at Hull, and that of the greater tides 14·6 inches, with a nearly regular gradation of increase in the intermediate groups. On the other hand, at low water, there was very little difference in the depression shown by the various groups, which would seem to indicate that at low water of springs the tide had not its full undulation. Again, in comparing the times, it would be seen that at high water the averages of the differences in the several groups were nearly constant, while at low water there was a regular gradation from the rapid propagation of the foot of the wave in 25 minutes at neap tides, to its more obstructed movement in 60 minutes, in the contracted low water channel of spring tides.

Simultaneous observations of this kind, at different points in one estuary, were of great interest, as illustrating the laws which governed the propagation of river tides under varying conditions, and as furnishing a step towards reducing the acknowledged theoretical principles to numerical values.

The Astronomer Royal was unable to say much upon the practical points of this subject; but would remark that the results just quoted were generally in accordance with those which theory suggested for river tides, with the exception of the difference of the height of mean tides at Grimsby and at Hull, which he could not conceive to be correct. He did not think that many similar observations had been taken in chains of stations at large tidal rivers; the only one he could refer to was that made, partly at his suggestion, under the direction of Colonel Colby in the river Shannon. The stations selected for this purpose were Kilbaha, Kilrush, Foynes Island, and Limerick. In those cases the elevation of mean water was referred to the same bench mark, and it was found that, in progressing up the river, the elevation of mean water increased successively from station to station. He was glad to find himself anticipated, in pointing out the effect of the great deep-water channel of the North Sea. The effect of the Dogger Bank, and

TABLE A.

Comparative Heights and Times of Tide at Hull, Goole, Naburn, and Gainsborough.

May and June, 1864.	Hull. Time.	Hull. Height.	Goole. Time of High Water after Hull.	Goole. Height above Hull.	Goole. Fresh.	Goole. Duration of Flood.	Goole. Lift of Tide.	Naburn. Time of High Water after Hull.	Naburn. Height above Hull.	Naburn. Fresh.	Naburn. Duration of Flood.	Naburn. Lift of Tide.	Gainsborough. Time of High Water after Hull.	Gainsborough. Height above Hull.	Gainsborough. Fresh.	Gainsborough. Duration of Flood.	Gainsborough. Lift of Tide.
	d. h. m.	ft. in.	h. m.	inches.	ins.	h. m.	ft. in.	h. m.	inches.	ins.	h. m.	ft. in.	h. m.	inches.	ins.	h. m.	ft. in.
Between 20 and 21 feet on Hull Gauge.	13 11 45	20 8	1 45	8	6	3 40	7 10	4 40	11	13	2 25	3 0	2 30	14	7	2 5	3 5
	23 45	20 11	1 45	8	9	3 55	7 9	4 30	15	15	2 30	3 5	3 20	5	1	2 35	3 5
	14 12 45	20 3	1 50	10	5	3 50	7 7	4 45	11	10	2 15	2 10	2 45	7	2	2 30	2 10
	15 1 0	20 9	1 40	9	8	3 55	7 9	4 15	8	10	2 15	3 1	3 30	5	1	3 0	3 3
	14 3	20 7	1 40	9	5	3 50	7 10	4 30	9	8	2 20	3 2	2 50	5	1	2 25	3 1
	16 2 10	20 10	1 40	10	8	3 45	7 11	4 35	19	10	3 0	4 1	3 20	6	1	2 30	3 5
	15 0	20 11	1 45	11	5	3 40	8 4	4 45	19	4	3 15	4 8	3 20	6	1	2 35	3 6
Means . .			1 44	9·4				4 34	13·1				3 5	6·9			
Between 21 and 22 feet.	12 10 45	21 5	1 45	11	10	3 25	8 5	4 25	13	18	2 10	3 6	3 10	10	12	1 55	3 5
	22 45	21 8	1 45	9	10	3 40	8 6	4 40	13	17	2 35	2 10	3 0	11	6	2 10	4 3
	17 3 15	21 7	1 45	13	7	3 40	9 0	4 20	19	17	5 35	4 3	3 15	7	1	2 30	4 3
Means . .			1 45	11·0				4 28	15·0				3 8	9·3			
Between 22 and 23 feet.	11 9 55	22 9	1 40	15	13	3 10	9 10	4 5	19	22	2 0	5 0	2 55	13	18	2 5	4 6
	22 0	22 11	1 40	15	14	3 30	9 11	4 0	17	23	2 5	4 11	3 0	11	14	2 15	4 10
	17 15 50	22 2	1 40	12	6	3 25	9 7	4 10	18	30	2 10	3 8	3 10	5	1	2 30	4 8
	18 4 10	22 7	1 35	13	7	3 25	10 0	3 55	14	19	2 20	4 8	2 55	5	0	2 20	5 2
	16 40	22 11	1 30	16	7	3 10	10 7	3 55	14	12	2 5	5 7	3 0	6	1	2 25	5 6
	28 12 10	22 3	1 35	11	5	3 10	9 8	4 5	9	2	2 15	5 4	2 25	1	8	2 20	4 10
	29 12 20	22 4	1 30	12	3	3 20	10 4	4 10	9	1	2 30	5 6	3 5	3	5	2 40	4 4
	30 1 25	22 11	1 35	7	5	3 15	10 0	4 10	3	2	2 10	5 6	3 20	4	0	2 30	4 9
	14 45	22 7	1 30	11	0	3 25	10 5	4 5	7	0	2 20	5 8	3 0	0	0	2 45	4 9
Means . .			1 35	12·4				4 4	12·2				2 59	4·4			
Between 23 and 24 feet.	10 9 20	23 10	1 25	18	15	3 0	11 0	3 40	23	28	2 0	5 11	2 55	18	30	2 15	5 0
	21 25	23 11	1 35	15	15	3 20	10 10	3 50	20	27	2 15	5 10	2 50	11	21	2 5	5 3
	19 4 50	23 3	1 30	17	8	3 10	10 11	3 55	16	12	2 15	6 1	2 55	8	1	2 15	6 0
	17 20	23 6	1 25	15	6	2 50	11 2	3 55	13	10	2 15	6 3	2 45	7	1	2 5	6 2
	20 5 35	23 10	1 25	14	7	2 55	11 4	3 45	15	12	2 0	6 7	2 55	8	3	2 15	6 5
	26 10 15	23 5	1 20	16	6	2 55	11 2	3 45	16	7	2 15	6 8	2 50	18	10	2 20	6 3
	27 11 5	23 2	1 15	14	3	3 5	11 1	3 50	12	3	2 10	6 11	3 10	2	6	2 30	5 6
	23 10	23 10	1 25	13	9	3 15	11 1	3 45	11	4	2 20	6 11	2 55	3	7	2 20	5 6
	29 0 15	23 9	1 25	14	8	3 20	11 2	3 50	7	1	2 25	6 9	2 55	2	5	2 25	5 8
	31 15 40	23 0	1 25	11	8	3 5	10 2	4 0	10	3	2 10	6 1	2 55	1	3	2 5	5 0
	1 3 45	23 8	1 30	13	5	3 10	11 3	4 0	9	3	2 15	6 8	3 0	2	3	2 15	5 9
	16 35	23 11	1 25	15	5	3 10	11 8	3 50	11	3	2 10	7 1	2 50	5	3	2 25	6 3
Means . .			1 26	14·7				3 50	13·6				2 55	7·1			
Between 24 and 25 feet.	21 6 10	24 10	1 20	17	10	2 40	12 6	3 35	20	21	2 0	7 3	2 45	9	10	2 10	6 11
	24 8 25	24 10	1 15	17	6	2 40	12 8	3 40	23	9	2 5	8 6	2 35	8	11	2 0	6 9
	29 22 15	24 2	1 20	11	7	2 55	11 5	3 45	7	4	2 0	6 11	2 45	2	8	2 15	5 10
	31 2 10	24 4	1 35	13	6	3 35	11 10	4 15	11	4	2 35	7 5	3 0	0	1	2 40	6 5
	2 4 50	24 10	1 15	17	7	3 5	12 7	3 40	14	5	2 15	8 1	2 40	5	6	2 15	6 11
	17 20	24 5	1 15	16	9	2 55	11 11	3 45	12	3	2 5	7 8	2 45	5	7	2 20	6 5
	3 18 5	24 10	1 15	17	8	2 55	12 6	3 45	13	3	2 20	8 2	2 40	5	10	2 15	6 7
	5 7 10	24 9	1 20	15	5	2 45	12 6	3 40	8	3	1 50	7 8	2 45	3	8	2 10	6 6
Means . .			1 19	15·4				3 46	13·5				2 44	4·6			
Between 25 and 26 feet.	9 8 40	25 0	1 20	21	19	2 45	12 1	3 35	27	37	2 0	6 8	2 35	21	36	2 15	5 11
	20 45	25 0	1 15	18	17	2 50	12 0	3 35	24	36	2 5	6 6	2 45	18	32	2 15	6 0
	20 18 0	25 0	1 15	16	6	2 50	12 9	3 30	16	15	2 0	7 7	2 40	7	4	2 10	7 5
	21 18 35	25 5	1 10	16	9	2 40	12 11	3 30	14	16	1 50	7 9	2 40	7	10	2 15	7 4
	22 6 55	25 2	1 20	21	11	2 50	12 11	3 30	19	13	2 10	8 2	2 35	10	12	2 15	7 2
	19 20	25 11	1 15	17	8	2 40	13 7	3 35	14	13	3 25	8 6	2 40	8	11	2 15	7 10
	23 7 35	25 6	1 15	18	11	2 45	13 0	3 25	17	10	2 0	8 7	2 30	10	15	2 5	7 3
	19 55	25 8	1 15	17	9	2 45	13 3	3 35	15	10	2 0	8 7	2 30	7	12	1 55	7 5
	25 9 15	25 8	1 5	16	8	2 40	13 3	3 30	14	8	2 15	8 8	2 25	6	14	2 10	7 2
	21 20	25 5	1 15	14	11	2 55	12 7	3 30	11	8	2 5	8 2	2 35	6	14	2 10	6 11
	3 5 40	25 0	1 15	21	7	2 55	13 1	3 35	14	3	2 0	8 5	2 40	4	8	2 20	6 10
	4 6 20	25 2	1 15	16	8	2 45	12 9	3 40	8	3	2 0	8 6	2 45	3	11	2 20	6 8
	18 40	25 2	1 20	16	8	2 55	12 9	3 40	8	1	2 5	8 3	2 50	3	9	2 5	6 10
	5 19 20	25 5	1 10	14	6	2 45	13 0	3 40	5	3	2 0	8 1	2 45	1	7	2 5	7 1
Means . .			1 15	17·2				3 34	14·4				2 38	8·0			

TABLE B.

To face page 512.

Comparative Times and Heights of High and Low Water at Hull and Grimsby, in May and June, 1864.

	High Water. Time. Hull.	High Water. Time. Grimsby.	High Water. Height. Hull.	High Water. Height. Grimsby.	High Water. Differences. Time.	High Water. Differences. Height.
	d. h. m.	d. h. m.	ft. in.	ft. in.	min.	ins.
Between 20 and 21 feet on Hull Gauge.	13 11 45	13 11 0	20 8	19 10	45	10
	23 45	23 30	20 11	19 11	15	12
	14 12 45	14 12 5	20 3	19 9	40	6
	15 1 0	15 0 30	20 9	20 1	30	8
	14 5	13 0	20 7	20 0	65	7
	16 2 10	16 1 40	20 10	19 11	30	11
	15 0	14 10	20 11	20 4	50	7
Means . .	.. ..	.. ..	.. ..	.. ..	39	8·7
Between 21 and 22 feet.	12 10 45	12 10 15	21 5	20 7	30	10
	22 45	22 30	21 8	20 10	15	10
	17 3 15	17 2 45	21 7	20 10	30	9
Means . .	.. ..	.. ..	.. ..	.. ..	25	9·7
Between 22 and 23 feet.	11 9 55	11 9 20	22 9	21 10	35	11
	22 0	21 45	22 11	22 1	15	10
	17 15 50	17 15 15	22 2	21 5	35	9
	18 4 10	18 3 35	22 7	21 7	35	12
	16 40	16 0	22 11	22 2	40	9
	28 12 10	28 11 20	22 3	22 1	50	8
	29 12 20	29 12 15	22 4	21 11	65	5
	30 1 25	30 1 0	22 11	21 10	25	13
	14 45	13 50	22 7	21 10	55	9
Means . .	.. ..	.. ..	.. ..	.. ..	39	9·6
Between 23 and 24 feet.	10 9 20	10 8 40	23 10	23 1	40	9
	21 25	21 0	23 11	22 8	25	15
	19 4 50	19 4 20	23 3	22 8	30	2
	17 20	16 40	23 6	22 7	40	11
	20 5 35	20 5 0	23 10	23 1	35	9
	26 10 15	26 9 25	23 5	22 8	50	9
	27 11 5	27 10 20	23 8	22 10	45	10
	23 10	22 45	23 10	22 9	25	13
	29 0 15	28 25 50	23 9	22 11	50	10
	31 15 40	31 14 35	23 0	21 10	65	14
	1 3 45	1 3 10	23 8	23 1	35	7
	16 35	15 40	23 11	23 1	55	10
Means . .	.. ..	.. ..	.. ..	.. ..	39	10·0
Between 24 and 25 feet.	21 6 10	21 5 40	24 10	23 7	30	15
	24 8 25	24 7 40	24 10	23 7	45	15
	26 22 15	26 21 45	24 2	23 3	30	11
	31 2 40	31 2 10	24 4	23 1	30	15
	2 4 50	2 4 10	24 10	23 7	40	15
	17 20	16 40	24 5	23 5	40	12
	3 18 5	3 17 20	24 10	23 9	45	13
	5 7 10	5 6 25	24 9	23 7	45	14
Means . .	.. ..	.. ..	.. ..	.. ..	38	13·7
Between 25 and 26 feet.	9 8 40	9 8 0	25 0	23 7	40	17
	20 45	20 20	25 0	23 7	25	17
	20 18 0	20 17 20	25 0	24 0	40	12
	21 18 35	21 18 0	25 5	24 4	35	13
	22 6 55	22 6 20	25 2	24 1	35	13
	19 20	18 40	25 11	24 9	40	14
	23 7 35	23 7 0	25 6	24 3	35	15
	19 55	19 40	25 8	24 9	15	11
	25 9 15	25 8 30	25 8	24 5	45	15
	21 20	20 50	25 5	24 1	30	16
	3 5 40	3 5 0	25 0	23 10	40	14
	4 6 20	4 5 45	25 2	23 9	35	17
	18 40	18 0	25 2	23 10	40	16
	5 19 20	5 18 45	25 5	24 3	35	14
Means . .					35	14·6

	Low Water. Time. Hull.	Low Water. Time. Grimsby.	Low Water. Height. Hull.	Low Water. Height. Grimsby.	Low Water. Differences. Time.	Low Water. Differences. Height.
	d. h. m.	d. h. m.	ft. in.	ft. in.	min.	ins.
Between 10 and 11 feet on Hull Gauge.	13 17 45	13 17 25	10 4	10 10	20	6
	14 18 55	14 18 30	10 3	11 0	25	9
	15 20 10	15 19 40	10 1	10 10	30	9
Means . .	.. ..	.. ..	.. ..	.. ..	25	8·0
Between 9 and 10 feet.	12 16 50	.. ..	9 7	error in record.		
Between 8 and 9 feet.	10 15 40	10 15 0	8 0	9 1	40	13
	11 16 10	11 15 45	8 10	9 1	25	3
	12 4 50	12 4 6	8 2	8 5	44	3
	13 5 35	13 5 0	8 7	9 4	35	9
	14 6 30	14 6 0	8 10	9 5	30	7
	15 7 35	15 7 0	8 10	10 5	35	19
	16 8 50	16 8 10	8 2	8 7	40	5
	21 20	20 45	8 10	9 7	35	9
	17 22 10	17 21 35	8 4	9 3	35	11
	27 17 25	27 16 45	8 7	9 3	40	8
	28 18 25	28 17 50	8 3	8 10	35	7
	29 19 40	29 19 0	8 6	9 1	40	7
	30 20 10	30 20 0	8 9	9 5	45	8
Means . .	.. ..	.. ..	.. ..	.. ..	37	8·4
Between 7 and 8 feet.	9 15 5	9 14 20	7 2	8 1	45	11
	11 4 15	11 3 20	7 2	7 10	55	8
	17 9 50	17 9 15	7 6	8 10	35	16
	18 23 15	18 22 20	7 4	8 1	55	9
	25 15 40	25 14 50	7 10	8 7	50	9
	29 7 20	29 6 15	7 5	7 11	65	6
	31 9 40	31 8 30	7 4	7 10	70	6
	22 3	21 10	7 8	8 3	55	7
	1 23 10	1 22 10	7 2	7 7	60	5
Means . .	.. ..	.. ..	.. ..	.. ..	54	8·6
Between 6 and 7 feet.	9 3 5	9 2 0	6 0	6 5	65	5
	10 3 35	10 2 40	6 8	7 1	55	5
	18 10 45	18 10 0	6 8	8 1	45	15
	21 0 40	20 23 40	6 2	7 1	60	11
	23 2 5	23 1 0	6 5	7 5	65	12
	25 3 35	25 2 30	6 4	6 7	65	3
	26 16 35	26 15 45	6 10	7 7	50	9
	27 5 0	27 4 15	6 2	7 1	45	11
	28 6 5	28 5 20	6 8	7 3	45	7
	30 8 25	30 7 30	6 5	7 1	55	8
	1 10 35	1 9 40	6 3	7 7	55	16
	2 11 35	2 10 40	6 6	7 8	55	14
	23 55	23 0	6 3	6 10	55	7
	3 12 25	3 11 20	6 1	6 7	65	6
	4 13 5	4 12 0	6 1	7 2	65	13
	5 13 55	5 12 45	6 0	7 1	70	13
Means . .	.. ..	.. ..	.. ..	.. ..	57	9·7
Between 5 and 6 feet.	19 11 40	19 10 40	5 9	6 10	60	13
	20 0 5	23 0	5 11	6 7	65	8
	12 5	20 11 20	5 7	6 9	45	14
	21 12 55	21 12 0	5 2	6 4	55	14
	22 1 20	22 0 20	5 8	6 5	60	9
	23 14 25	23 13 20	5 7	6 7	65	12
	24 15 5	24 14 5	5 4	5 10	60	6
	26 4 20	26 3 25	5 7	6 1	55	6
	4 0 50	3 23 45	5 8	6 5	65	9
	5 1 35	5 0 20	5 3	5 11	75	8
Means . .	.. ..	.. ..	.. ..	.. ..	60	9·9
Between 4 and 5 feet.	22 13 40	22 12 40	4 8	6 1	60	17
	24 2 50	24 2 0	4 5	5 2	50	9
Means . .	.. ..	.. ..	.. ..	.. ..	55	13

the Wells Bank, and the deep water between them and the English coast, and the way in which it affected the character of the great tidal wave of the North Sea, required careful consideration. It had been pointed out that the impact of the water came up the deep sea-channel and fell upon the Holderness coast. That served to explain a curious point, as to the course which the tide took up the Humber in different periods of its flow. Mr. Coode had stated that the first set of the rising tide into the entrance was towards its south-western bank, passing south of an island shown on the charts, but that afterwards it went to the north of that island and had a straight course up the river. Now, the circumstance of the water flowing up the deep-sea channel, with a sort of impact coming from the north, served in some measure to explain that statement. In a tidal river the water was slack about the time of high water, but it was not so in the open sea, where it was slack about three hours before and after high water; and at high water, in a very open sea, the particles of water had their greatest velocity in the direction in which the wave travelled. In a sea partly open, like this deep-sea channel, there was something intermediate between these two conditions, and he conceived it possible that the water was stationary in this deep-sea channel perhaps one or two hours after high water. To that time, but no longer, the water was flowing up the sea channel. He should think, therefore, for some hours before high water, and even after the time when the water in the sea-channel was highest, it was rushing down towards the south with great velocity, and thereby acted upon the southern part of the channel, driving all the tidal water in that direction; but before the water had filled the Humber, the sea-water had come to its stationary point, and the flow was merely a quiet flow, filling the channel of the river, but not coming with an impact on the south-west side. It was well to be prepared with general principles of this kind in reference to future cases of tidal phenomena, which might present themselves in the examination of other estuaries. In the Treatise on "Tides and Waves," in the "Encyclopædia Metropolitana," published in 1840, he called particular attention to the effect of the Dogger and the Wells Banks, and the deep sea separating them from the coast of England, which he regarded as the key to the explanation of all the remarkable phenomena presented by the tides in the North Sea, especially of the inversion of the order of the tides on the English and the Dutch coasts. A special engraved map was principally devoted to this explanation.

Mr. T. Webster, Q.C., understood from Mr. Parkes that the low-water level in certain rivers had been considerably depressed, without a corresponding or even any elevation of the high-water level. Now it was well known that the contrary had taken place

in the Nene and the Ouze. Great improvements had been made in those rivers; and invariably the engineering operations, which had depressed or lowered the low-water level, had also raised the high-water level. He did not say that the elevation of the high-water level would be equal to the depression of the low-water level. That would depend upon local circumstances; but he was startled at hearing the statement, accompanied as it was by tabulated details, that upon a certain river there was a depression of the low-water level, and no elevation of the high-water level. Suppose that in a large open estuary communicating with a river which had its own peculiar constitution, what he would call a horizontal mass of water, with very small vertical dimensions, was converted, by means of engineering operations, into a wedge form having small horizontal and large vertical dimensions. That was the operation carried on in the improved rivers, and was due to the particles of fluid moving *inter se* without appreciable resistance. He could hardly conceive a case in which there would be a depression of the low-water level without some elevation of the high-water level. In the Nene there was an average depression of the low-water level, from 6 feet to 10 feet, below Wisbeach. Then there were the cases of the Tyne, the Mersey, and of the Clyde. In the Mersey the effects were not consequent solely upon modern engineering operations, but upon a physical state of things which engineers sought to imitate to a certain extent. In the Mersey it was an undisputed fact, that there was a regular heaping up of the tide at different stages, due to the operation of the laws of Nature, the conversion of a mass of fluid from a flat horizontal wedge into a vertical and deep wedge. Proceeding from the mouth to Liverpool, the contraction at New Ferry, and the further contraction at Runcorn, led to an accumulation of tide at the latter place several feet above what it was at the mouth. That was due simply to the operation of momentum acting on the particles of water, and changing the volume from a shallow flat into a deep vertical mass.

Mr. Harrison, Vice-President, said it was perfectly consistent that the state of things to which Mr. Webster took exception should exist. Take the case of the Tyne. Improvements had been going on there to a large extent. The embouchure of the river had been increased by the removal of rocks and by the lowering of the bar by dredging, and no doubt a much larger quantity of water now flowed into the Tyne every tide than before. He believed that the high-water level had not been increased at Newcastle, although the time of high water was earlier, and that the tides ebbed out fully 2 feet lower than formerly. The lowering of the low-water level of a river was one of the best tests of its improvement. The Mersey was not dependent upon the mere flow of a well-regulated channel, as in the river Tyne, but was more of the nature of an estuary. At Chep-

stow, the rise of tide was 50 feet; but that was due to the trumpet-mouthed form of the channel.

Mr. Shelford, in reply upon the discussion, said that Mr. Bateman thought the fact of the North Channel being used as a harbour of refuge was a practical objection to the reclamation of the indent. The Paper was incorrect in dealing with the North Channel. It stated that the eddy in the flood tide 'keeps it from silting up.' It ought rather to have said 'keeps it from silting up at once,' because it was, in fact, gradually silting up at the present time.

He thought the indiscriminate adoption of the maxim, as to the non-exclusion of tidal water, adduced by Captain Calver, was wrong. In much that Captain Calver had said he mistook the object of the Paper and the diagrams by which it was illustrated.

Mr. Coode referred to the tidal currents shown on Captain Calver's chart. He wished to explain that the statement in the Paper with regard to those observations was scarcely correct. He found that the lines on a plan by Mr. Coode showed the result better than his own, and he had adopted them. The strongest reason he knew against the construction of the groynes along the coast, to prevent the destruction that was going on, was that there was no object to be gained by it, except the preservation of the lighthouses. Mr. Coode had referred to the fact of the Foul Holme Sand having increased. No doubt that was so; but he considered it was due to a local cause—the improved tidal action since 1828, which, he contended, had caused a great scour opposite Sunk Island. In consequence of that scour, a portion of the silt had been carried up the river, and been deposited at Foul Holme Sand, and he believed it was owing to that local cause that the river had been deteriorated. The comparison shown between 1828 and 1852 might be generally relied upon. The Board of Trade had charge of the Spurn, and had strongly opposed the reclamation of the indent, although it was obviously the easiest way of enabling the Spurn Point to retire, and the landowners had offered to do the work at their own expense. Mr. J. T. Harrison mentioned £1,200 a year as the loss due to the encroachment of the sea. But what works could be effected for £1,200 a year to protect a coast 30 miles in length, with deep water close to it? Besides, if the degradation of the Holderness coast were stopped, the lengthening of the Spurn Point would also be stopped. It was worth notice that the Spurn advanced most rapidly when the channel south of the Bull Sand formed most rapidly. In Collins' chart the sand was shown only half a fathom in depth; and in less than one hundred years after it had greatly increased. Between those two periods the Spurn had lengthened about a mile. Mr. Bartholomew doubted the accuracy of the statement as to the increased range of the tide; principally owing to his observations at Goole.

Fig. 1, Plate 21, showed that there had been no important alteration in the tides at Goole since 1725; but at Hull there was no question that the range between high water and low water had increased. In 1725 the range of spring tides at Hull was 18 feet; it was now 22 feet or 23 feet. Mr. Parkes' comparison between the tides at Grimsby and at Hull was not, he thought, sufficiently precise. If the observations taken at Spurn Point and at Hull were examined, it would be found that the Grimsby observations were corroborative, and were also confirmed by Captain Calver's.

However important the reclamations that had taken place might be, the interest in the present condition of the outfall of the Humber seemed to centre in Spurn Point, where two great actions were going on. The first and most important, which was entirely detrimental, was an abrasion or scooping out of the Lincolnshire shore by the flood tide as it entered the Humber. Then there was the degradation of the Holderness coast, and the consequent accumulation of shingle at the end of Spurn Point and seaward of it—an action partly detrimental, and partly beneficial; detrimental, as it tended to the formation of a bar across the Humber; but beneficial, as it enabled Spurn Point to adjust itself to the southward movement of the river, and so to conserve, if not to improve, the tidal energy.

He appreciated the cautionary remarks from Captain Calver as to dealing with so large an estuary as the Humber. He admitted that any engineering work carried on in the Humber should be on right principles; and he contended that the works on the seaward face of Spurn Point were on wrong principles, and the longer they were continued, the more complete would be the ultimate destruction of the present Spurn Point. The point to which the attention of those interested in the outfall should be directed was the scooping out of the Lincolnshire shore; in reference to which, he believed that every drop of tidal water which entered the Humber, and did not contribute to the useful action of the ebb tide, was positively injurious.

In conclusion, he had endeavoured to bring before the Institution four main points,—first, that three-fourths of the estuary had been reclaimed; secondly, that the reclamation was accompanied by, but was not the chief cause of, an improved tidal action; thirdly, that one source of decay was the scooping out of the Lincolnshire shore; and, fourthly, that another source of decay was the accumulation of shingle seaward of Spurn Point. He thought, notwithstanding what had been said, that those points were proved, and might be accepted as facts.

May 4, 1869.

THOMAS HAWKSLEY, Vice-President,
in the Chair.

The discussion upon the Paper No. 1,216, "On the Outfall of the River Humber," by Mr. Shelford, was continued throughout the evening.

The following Candidates were balloted for and duly elected:—VALENTINE GRÆME BELL, VALENTINE BROWNE, BENJAMIN SHAW BRUNDELL, JAMES BUCHANAN EADS, CHARLES CAULFEILD FISHE, GEORGE FISHER, FERDINAND WILHELM WEGHORST LÜDERS, RICHARD MORELAND, Jun., and BERNHARD SAMUELSON, M.P., as Members; JAMES CLARK BUNTEN, JOHN COLLINSON, EDWARD GERSHOM DAVENPORT, ALBERT CHESTERFIELD JENOUR, HENRY DE LA POIRE MURPHY, JOHN NOBLE, FRANK BAILEY PASSMORE, THOMAS CHEVELEY RAYNER, ALFRED TERRY, ALFRED ANTHORN WICKENDEN, and JOHN STEDDY WINBOLT, M.A., as Associates.

It was announced that the following Candidate, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, a Student of the Institution:—CHARLES PRESTON GIBBONS.

May 11, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—John Henry Abbey, Edward Brotherton Carroll, James Farrar, Frank Garrett, Henry Newson Garrett, James Howard, M.P., Harry Edward Jones, Thomas Miller, Frederick Peck, Henry Minchin Simons, and James Williams, as Associates.

Mr. Gregory. President, said since he last occupied the chair he had visited Paris, accompanied by Mr. Bidder, Mr. M'Clean, Mr. Cubitt, Mr. Hemans, and Mr. Manby, as a deputation, to present to the Emperor of the French the Diploma of Honorary Member of The Institution of Civil Engineers. His Majesty received the Deputation most graciously, and desired them to convey to the Members of the Institution his sincere thanks for the honour they had conferred upon him, and the gratification it afforded him to become a member of the Society. The cordiality which marked the official reception, and the gracious and even friendly hospitality which followed it, showed that the illustrious Honorary Member fully appreciated the compliment so justly paid to his scientific attainments, and to his unwearied interest in the progress of public works, and that he desired, through the representatives of the Institution, to do honour to the Engineers of Great Britain.

No. 1,219.—"Description of the Low Water Basin at Birkenhead." By John Ellacott, M. Inst. C.E.

The plans sanctioned by Parliament in 1844 (Plate 23, No. 1), for the conversion of Wallasey Pool on the Cheshire side of the Mersey into docks, comprised, among other works, a deep and capacious Basin, communicating with a Float or Wet Dock, of large area, intended for the accommodation of shipping, and also to serve as a reservoir for scouring and maintaining the Basin at its proper depth. As due to its immense size, the former of these works, having a proposed area of 37 acres, was designated the Great Low Water Basin, while the latter, set down at 150 acres, became known as the Great Float. Other works of an important character were included in the project, but the two mentioned, of which the Basin constituted the main feature, were the most noteworthy—the Basin being specially intended as a place of resort and refuge

for shipping at all states of the tide, wherein the risk and inconvenience arising from exposure at anchorage in the open stream of the Mersey would be avoided. (Plate 22.)

The situation chosen for these works was shown to possess special advantages for commercial purposes, inasmuch as the water on its shore was deeper than on the Lancashire side, and therefore better suited for the maintenance of a Low Water Basin; and further, the prevailing winds being westerly, were also more favourable, for thereby the passage of vessels in and out of the Birkenhead Docks could be conducted with much greater ease and safety than at the docks on the Liverpool side.

The site fixed on for the Low Water Basin was at the opening of Wallasey Pool, on the foreshore of the Mersey, nearly midway between the ferry landing-places of Woodside and Seacombe. The mouth of Wallasey Pool embraced an area of about 150 acres, of which the basin was to occupy, as already stated, 37 acres, leaving on its north and south sides two large spaces of tidal land, which, when afterwards reclaimed, became generally known as the North and South Reserves.

Between 1844 and 1853 several alterations were made in the dock plans, and among others the Low Water Basin was reduced in area from 37 acres to 27 acres, and its form was changed. (Plate 23, No. 2.)

The line of direction of the river Mersey at this part is nearly due north, the true bearing being N.N.W., and the proposed basin was intended to enter from the river at a right angle in the form of a broad channel running westward for a length of 1720 feet, and having a width varying from 350 feet at the mouth to 400 feet at the western end. On the south side of this channel an arm or fork was projected, in a south-westerly direction, for a mean length of 1,350 feet, with a width at the remote end of 520 feet, contracting, as it approached the main channel, to 320 feet. This arm was designated the Birkenhead Fork, as distinguished from the direct channel or main fork, and the irregular combined figure thus formed was known as the Great Low Water Basin.

The depth of the Basin was to be 20 feet 9 inches below the Old Dock Sill, the datum level of the port; and the great advantage to be obtained by this depth was shown by contrasting it with the depths of the sills of the outer docks at Liverpool, the lowest of which was no more than 6 feet 8 inches below the datum, and where, for want of water at neap tides, it frequently happened that many of the deep-laden class of vessels were unable to get in or out of dock.

The vertical range of the tides at the Port of Liverpool is on the average of springs, exclusive of the equinoctial tides, 27 feet 6 inches, the level of low water being 8 feet 8 inches below the

datum. It followed, therefore, that the basin would have a depth of water within itself of not less than 12 feet at dead low water of spring tides, and would thereby afford accommodation for vessels of moderate draught at all times.

The embankment or wall, called the Great Dam, at the head of the main fork of the basin was to have one tidal entrance through it 100 feet in width, with the sill laid at the level of 10 feet below the Old Dock Sill, and on the opposite side from this entrance, and alongside the southern quay of the western end of the main fork, was the great lock, 500 feet in length and 100 feet in width, having its outer sill 18 feet 6 inches and the inner sill 10 feet below the datum. Through this lock all vessels to or from the Float were to be passed at nearly all hours, when the gates of the large tidal entrance were closed. At the head of the Birkenhead Fork there was a small entrance and lock.

The Basin having been formed to the before-mentioned depth was to be maintained at that depth by the frequent discharge, through sluices, of water from the large dock, or reservoir, called the Great Float. To effect this object the walls at the heads of the two forks were to be constructed with sluices, so designed as to pour forth, for the whole width of each head, a stream of water as nearly as possible in the form of a continuous sheet. The sills of these sluices were to be laid about 2 feet above the bottom of the Basin, and the sluices were intended to operate, not in the usual way, by discharging a large body of water tearing up everything in its course, but as a sheet of water that could be regulated to any degree of force by means of sluicing paddles.

The current, when discharged from the sluices, was intended rather to prevent an accumulation of deposit in the Basin, than to remove it after it had been once allowed to form; and for that reason the water was to be run out as often as the tides would permit, at a velocity three or four times greater than the flow of the tide into the Basin, and therefore sufficiently powerful to remove any matter that might be brought in. The velocity here spoken of was intended to produce the effect of a river passing through the Basin with a gentle current, not strong enough to hinder vessels of light draught from remaining therein during the operation; on the contrary, it was assumed that the scouring process would be more effectually carried on while the vessels were there than if the Basin remained unoccupied.

It was strongly maintained, that although the proposed system of sluicing was entirely new, and that nothing known would in any respect bear analogy to it, still there could be no doubt whatever as to its success; the scouring water was to flow through the Basin like a sub-aqueous river, sweeping along the bottom with scarcely any disturbance of the surface; there would be no eddies,

or foul currents, as were known to exist under the ordinary modes of sluicing; the surface of the water would not be much agitated; there would be no bubbles rising up, neither would there be any tearing away of the bottom.

The great works, which had occupied the attention of Parliament for many successive sessions, were not destined to be carried out in the form originally contemplated. The projectors of the Birkenhead Docks failed to accomplish their undertaking, and in 1855, when the estate had fallen into considerable difficulties and become altogether insolvent, the whole of the property was transferred to the Corporation of Liverpool, to be, in 1858, again transferred and vested in the Liverpool Dock Trustees, under their newly accorded title of the Mersey Docks and Harbour Board.

A new era now opened for Birkenhead. The authorized plans originated by the late Mr. Rendel (Past-President Inst. C.E.) were set aside, and those of Mr. John B. Hartley (M. Inst. C.E.) were substituted.

The Low Water Basin, insisted on by Parliament, was still a prominent feature in the scheme, although altered in form and considerably reduced in size. (Plate 23, No. 3.) Its position on the foreshore remained nearly the same as at first, and it still lay at right angles to the river, but the southern fork was lopped off, and it now took the form of a single channel, 1,750 feet in length, 400 feet wide at the western end, and 300 feet in width at the mouth. Its depth was to be 21 feet below the Old Dock Sill, and its area 14 acres. In a recess on the southern side a landing stage, 1000 feet long and 35 feet wide, was to be placed, having two bridges of communication with the quay.

The primary object of the Basin remained the same. It was still to be an open deep-water harbour, into which vessels might run and remain, or be 'locked' at once into the Float. Its depth was to be maintained by a scour of water from the Float run daily, or as often as the minimum height to which the Float was restricted—namely, 13 feet on the Old Dock Sill—would permit.

The words of the Act describing the Basin are as follows:—"A great Low Water Basin opening into and communicating with the Great Float, by means of a lock 50 feet wide and 240 feet long, and having sluices of not less than 800 feet sectional area, for the purpose of drawing water therefrom, for scouring and deepening the said Low Water Basin." The plans were prepared with a view to produce a result similar to that intended by Mr. Rendel; the water was to flow from the sluicing orifices as nearly in the form of a continuous sheet as a due regard for the stability of the structure would permit, and it was to open on to the Basin at about 2 feet 6 inches above the bottom.

From 1855 to 1858 the works were prosecuted by the Corpora-

tion of Liverpool, and were entirely confined to the deepening of the Great Float. On the 1st January, 1858, the transfer to the Mersey Board took place, and in July of the same year the Act for the altered plans was passed, and the works in their existing form commenced.

The site of the dam within which the sluices and lock entrance at the head of the basin were to be built, occupied to a large extent the line of the old channel running down to the river from Wallasey Pool, and consisted of mud and soft deposit to a considerable depth. Nearly the whole area of the dam—amounting to about 3 acres—had to be prepared by piling for the reception of the masonry of the several works. (Plate 24, No. 2.)

The piling was of three kinds: first, bearing piles of Baltic timber, in logs 13 inches by 13 inches, and varying from 12 feet to 20 feet in length, driven over the whole surface of the ground, at distances of 4½ feet apart from centre to centre; secondly, close-sheeting piles of Baltic timber 12 inches in thickness, grooved and tongued, driven in five parallel rows between the Basin and the Float, the outer rows being driven in front of the walls on each side, and the others at about equidistant spaces between them; the third consisted of other and shorter cross lines of close-sheeting driven in certain places through the body of the work. The object of the second and third kinds of piling was to cut off any sub-communication between the Float and the Low Water Basin, through the loose spongy soil along the line of the old channel. The heads of the piles were levelled off, and the ground between them excavated to a depth of from 18 inches to 2 feet, and filled up with concrete. An open-work of cross planking 6 inches in thickness was laid on the heads of the piles.

At a short distance to the northward, but still within the dam, a large well, with a division wall across it forming a double well, was sunk. This was for the purpose of drying the works during their progress, and also for exhausting the chambers and portions of the dock entrances after their completion, with the view to future examination and repair.

The width of the dam from the head of the Basin to the Float is 350 feet, having the lock entrance, 50 feet wide and 240 feet length of chamber, formed therein. The outer sill of the lock is laid at the level of 12 feet, and the inner sill at 9 feet, below the Old Dock Sill. The lock is also provided with reverse gates towards the Basin.

The arrangements for sluicing consist of two chambers, or passages, leading from the Float, each 30 feet in width, and placed one on each side of the entrance lock. These chambers were furnished with gates similar to a dock entrance, and provision was also made for closing the end of each by means of a caisson. The inner sills

were laid at a level of 8 feet below the Old Dock Sill (Plate 25); the floors were inverted, and fell away from the Float at an inclination of 1 in 33 for a length of about 200 feet, where a level of 15 feet below the Old Dock Sill was attained; they then dropped rapidly, and in a length of 25 feet reached the 18-feet level, at which they continued, for a distance of 45 feet, to within 15 feet of the mouths of the sluices. In the latter length there was a slight fall of 6 inches.

The sides of the chambers were built of large-size Wallstone masonry, and the 30-feet width was continued from the commencement at the Float for a distance of 220 feet (Plate 24); they then began to open out by a gradually enlarging width, until each finally closed at the back of its respective sluices, wide enough to embrace the whole group on one side.

The top of each chamber was uncovered for a length of 77 feet from the Float (Plate 25); it was then arched over for a length of 29 feet, the clear height to the crown being 30 feet 10 inches. The crown then suddenly dropped to 19 feet, at which height it continued until it reached the point where the sides began to expand, and where the crown rose into the form of a dome immediately behind the wall at the head of the Basin. Air shafts were carried up through the chambers, and the ground above was paved and finished at a level to correspond with the adjoining quays.

The thickness of the wall forming the head of the Basin and containing the sluices averaged 49 feet. The sluices were twenty in number, and with the lock entrance extended the whole width of the basin. Ten of the sluices were on the north, and ten on the south side of the lock. The leading channel of each sluice was straight-sided, measuring 5 feet 2 inches horizontally by 8 feet vertically, and giving a sectional area of 41 feet 4 inches for each sluice, or a total area for the twenty sluices of 826 feet 8 inches. The channel extended in this form and size for a length of 27 feet, being the space within which the sluice paddles were placed. At the chamber end each sluice widened out horizontally, and to a slight degree vertically, but towards the Basin the shape altered considerably, the crown dipped, and the sides separated, until the aperture at the point where it met the Basin became 4 feet 6 inches high, by 12 feet horizontal width.

The division walls separating the sluices were each 9 feet in thickness, and built of granite, in large clean-dressed blocks. The central divisions were 53 feet, and those at the sides 45 feet, in extreme length. The ends of the division walls towards the chamber were of various rounded forms, suited to the position of each, while towards the Basin they were all set out alike. The sills of the sluice openings were set at the level of 18 feet 6 inches below

the Old Dock Sill, and immediately outside, and in the Basin, a stone apron was laid, with its surface forming a continuous slope with the sills for a distance of 30 feet, where a line of 12-inch sheet piling was driven, and where the level of the bottom of the Basin was met, namely, 21 feet below the Old Dock Sill. The whole width of the apron was 80 feet, and it was laid with large-size stone blocks, 5 feet in thickness on the side next the sluices, and 3 feet thick for a width of 50 feet in the Basin.

The sluicing paddles were of green-heart, wedge-shaped, 6 inches thick at the point and 24 inches at the butt. In addition to each single working paddle, provision was made for a second and outer paddle of the like dimensions, to be available in case of accident to the inner one. Preparation was also made for a third paddle of iron, which, sliding in a groove outside the other two, was for use only when examination or repair was necessary to the appliances within. The working paddles and their duplicates were all provided and brought into use, but the outer iron paddles, although prepared and the masonry made ready for their reception, were not fitted.

All the masonry connected with the sluices, the sills, heads, and division walls, the paddle jambs, and also the sides of the chambers where they approached the outfalls, were of wrought granite, in large blocks, smooth-dressed, and carefully built.

Hydraulic power was applied for lifting and lowering the paddles. In a large building (Plate 24) adjoining the wells already alluded to were placed two high-pressure steam-engines of 112 H.P. each, with two accumulators, forming the source whence the power was derived for working the sluices, and likewise the gates, bridges, and other appliances on the eastern portion of the Birkenhead Docks. The power was so applied, and connected with suitable machinery, that one or more of the paddles, or the whole simultaneously, could be raised or lowered, swiftly or slowly, as might be required at one time. The tops of the paddles, shafts, and the upper gearing, were housed in and protected by single story sheds erected on the quays.

In addition to the provision already described for maintaining the Basin at its proper depth, two large culverts, each 7 feet high by 6 feet in width, were built within the north and south side walls. These culverts terminated at the pierheads in a group of small outlets, and were intended for clearing away any deposit which, having been driven down the Basin by the action of the main sluices, might find a resting place near the wings, and within the line of current alongside the river wall. The culvert in the south wall was also provided with suitable openings for scouring away any deposit that might gather underneath the landing stage.

On the morning of the 18th of June, 1863, the masonry of the

walls of the Basin was finished, and the recess on the south side was being prepared for the reception of the landing stage and its bridges. The Contractor for the excavations had completed all the work within the temporary dam, which stretched across the mouth of the Basin, and was engaged in the final operation of gathering up and removing the loose materials and plant. As the foreshore on which the dam was seated was considerably higher than the finished bottom of the Basin, the excavations had been carried (with the view to lessen as much as possible the subsequent dredging) nearly close up to the inner line of the dam, and some of the shores that it was considered safe to remove had been taken away. The work was thus far advanced when, on the morning tide of the above-mentioned date, the dam suddenly burst in for about one-third of its length, leaving two ragged ends standing; the floating wreck of broken piles, walings, and other timber, being swept in a confused mass to the head of the Basin.

Beyond the destruction caused to the materials of the dam, there was not much mischief done; but the sea, in bursting through, swept a hole out of the bottom just within the dam, and taking the disturbed rubbish, roughly estimated at about 20,000 cubic yards, in its onward course deposited it again over the middle and towards the upper end of the Basin.

Before a commencement could be made with the sluicing, it was necessary to clear away the remainder of the dam, and also to make some progress in dredging down the site it occupied and the bed of the river outside. These operations took up much time; moreover, the hydraulic machinery, although well advanced, was not fit for use; and hence it was not until January, 1864, that everything was ready, and the first trial of the sluices took place.

Prior to this event an attempt had been made to run the water through the culvert in the south wall of the Basin, with a view to clear away some rubbish that remained at the foot of the pier after the removal of the dam. But from some cause, which was never clearly accounted for, such a violent shock was communicated to a portion of the masonry forming the back of the landing stage recess, that the wall was instantly forced over 5 inches out of the perpendicular. Except for the purpose of sluicing underneath the landing stage, no further attempt was made to run the water through the culvert. No trial was ever attempted of the corresponding culvert on the north side of the Basin.

The time chosen for the first sluicing trial was at low water of the morning tide on the 20th January, 1864. The water in the Float stood at 15 feet 3 inches above the Old Dock Sill, and 1 foot above in the Basin; the difference of level, or head, was therefore 14 feet 3 inches. The centre of the sluice opening was 31 feet 6 inches below the level of the water in the Float.

The Basin having been open to the tidal flow since the bursting-in of the dam, had received a considerable amount of deposit, in addition to that acquired by the clay-filling of the dam and the rubbish scooped out of the hole; the two latter alone causing an average thickness of 10 inches all over the bottom. The depth of the basin, when the excavations were completed, was 21 feet below the Old Dock Sill, but now the average depth was only 18 feet 4 inches, showing that a deposit of 32 inches had accumulated since the destruction of the dam, a period of about seven months.

At the first opening of the sluices, the chief attention was directed to the working of the machinery; the paddles were slowly lifted and lowered, sometimes singly, at other times in sets of a few only, and then altogether. Subsequently, and when it had been satisfactorily proved that the machinery was well under control, the clearance of the basin down to its primary level became the sole object aimed at, and hence it happened that but few trials of an experimental character were afterwards made.

The condition of the water on first leaving the sluices was that of a rushing torrent of white foam, through which, and between the central sluice apertures, occasional glimpses were caught of the stone apron below. Commencing on one side of the Basin, the lines of direction of the current tended, with a boiling, tumbling motion, towards the opposite side from whence they set out. In their course towards the river, the tendency was to oscillate from side to side, forming, for the most part, a series of long curved lines, much broken into and disturbed by an irregular action constantly going on in the central spaces between them. While the main current, increasing in breadth as it approached the river, would be running in a series of bends at the rate of 8 miles and upwards an hour, the intervening portions would be moving slowly and irregularly in various directions. Sometimes, at the close of the operations, the current would gradually reverse itself, and finally set into the Basin for a short distance, at an estimated rate varying from half a knot to two knots an hour.

Soon after the sluicing had commenced, the colour of the water would be seen to change; a dark brown cloud would rise, and, moving slowly with the rolling mass, would gradually extend itself to the mouth of the Basin and out into the river. It was also observed that, at a distance of about 150 feet from the head of the Basin, a cross mound of water would rise from 12 inches to 18 inches higher than the natural level, and would fall off with a long slope on the opposite side, caused apparently by the impetus of the outflowing water driving on and heaping up the comparatively still water with which it had come into sudden contact.

The disturbance of the water was very great, and nothing afloat

could live in the Basin while the sluices were in operation. On the second occasion of running the sluices, the paddles on the north side had to be promptly closed, on account of the breaking away from her moorings of a wrecked vessel of 1,400 tons, which had been allowed to enter and take the ground in the Basin.

Before giving the result of the sluicing operations, and the effect produced by the scour, it will be convenient to mark the several events which occurred during the different trials, and which largely contributed towards the change that was subsequently decided on, namely, to abandon the Basin as a Low Water Tidal Basin and to convert it into a Wet Dock.

On January 25th, during the fourth trial of the sluices, the gates of the north channel were torn from their fastenings and swept into the chamber. The paddles were immediately lowered, and all further sluicing operations suspended, until an examination of the channel and chamber had been made. It was found, on investigation, that no damage had been sustained beyond the injury to the gates, but that, in some unaccountable way, a pile had been washed into one of the sluices and become jammed underneath the paddle, thus preventing it from being closed.

The trials were resumed and continued at suitable intervals until the 21st of July, when the gates of the south sluicing chamber were carried away in a similar manner to the former, and, in consequence, the operations were again suspended.

From sections taken across the Basin after every set of trials, it was soon discovered that a portion of the bottom, immediately beyond the stone apron, was being gradually washed out, and by the 22nd of August, a hole, 6 feet in depth, had thus been formed. All attempts to fill up and reduce this hole, by discharging large blocks of rubble stone into it, were ineffectual, and after the 15th of November, 1864, when the last trial of the sluices was made, it was found that the sheet piling in front of the apron, on the margin of the hole, was bare on the face to a depth of 4 feet, sloping down suddenly to a depth of 9 feet below the finished bottom of the Basin. The piling had also parted from the masonry of the apron, leaving a space between the stonework and the heads of the piles of from 3 inches to 9 inches.

On the 23rd November the water was pumped out of the north chamber, and an examination showed that the masonry therein had sustained considerable damage. The side walls and upper portions of the interior were uninjured, but a large quantity of the floor immediately at the back of the sluices had been torn up, and the concrete and piles laid bare in several places. No remains of the broken-up masonry were found in the chamber, all had been carried out into the Basin, except one sandstone ashlar block, which being too large for the opening, had become jammed in one

of the central sluices. A subsequent examination of the channel leading to the south sluices showed that similar damage, though not to the same extent, had taken place in the floor of that chamber.

Prior to the commencement of the sluicing operations in January, 1864, a deposit, as already stated, had accumulated over the bottom of the Basin to an average thickness of 32 inches. The results of those operations, which extended over a period of ten months, are as follows:—

Dates of Sluicing, 1864.	Number of Days Sluicing.	Total time occupied in Sluicing.		Average thickness of deposit remaining on the bottom of the Basin after Sluicing.
		hrs.	min.	inches.
January 20, 22, 23, 25	4	3	23	31
March 22, 23, 24, 26	4	1	54	31
April 11	1	0	30	35
May 4, 5, 6, 7, 9	5	2	46	27
June 4, 6, 7	3	1	7	25
June 20, 21, 22, 23, 24, 25	6	2	4	23
July 4, 5	2	0	34	19
July 18, 19, 20, 21	4	0	55	19
August 16, 17, 18, 19, 20, 22.	6	2	17	16
August 31, September 1, 2, 3	4	1	23	15
September 14, 15, 16, 17, 19	5	1	51	13
October 1, 2	2	0	39	13
October 13, 14, 17, 18	4	1	24	14
October 31, November 1, 2, 11, 14, 15	6	1	58	14
Total	56	22	45	

These results show, on the whole, a decided lessening in the thickness of the deposit, it having been reduced from 32 inches, at which it was found in January, to 14 inches in November. The apparent anomalies, on some occasions, where an increase appears after sluicing instead of a diminution, arose, in some measure, from the tearing up of the bottom and the subsequent deposit of the disturbed mass over other parts of the basin. In stating the thickness of the deposit remaining after the several trials, no notice has been taken of the depths found below the 21-feet level, in some places considerable, especially immediately in front of the apron. Had these extra depths been included, the minimum average thickness of the deposit would have been 4 inches only. The quantity of material removed is thus shown to be an amount represented by an average depth over the Basin of 28 inches. One inch in depth contains 1,850 cubic yards, and therefore the whole depth of 28 inches is equivalent to a total quantity of 51,800 cubic yards.

But in addition to this amount, there is also to be taken into account, the daily quantity carried into the Basin by the recurring tides, during the forty-three weeks the sluicing operations were continued. An estimate may be formed of this quantity by observing that, from the time of the breaking in of the dam to the commencement of the sluicing, there was an interval of thirty-one weeks, and during that period the accumulation of deposit was 32 inches in depth, representing a total quantity of 59,200 cubic yards. Deducting from this quantity the 20,000 cubic yards estimated to have been carried in with the wreck of the dam, there remains a total accumulation of 39,200 cubic yards for the thirty-one weeks, or an average deposit of 1,264 cubic yards per week.

There is reason to believe, as will be shown hereafter, that the actual deposit was somewhat greater than this; but assuming it to have been no more, then the total deposit due to the tides for the forty-three weeks would be 54,300 cubic yards, which, added to the original deposit, would amount in the whole to 106,100 cubic yards.

The number of times, or days, on which the sluices were run was fifty-six, and the aggregate duration of the operations, including the time occupied in opening and closing the paddles, was $22\frac{3}{4}$ hours. The lifting of the whole of the paddles could be accomplished in from four to ten minutes, and the lowering of them in about the same time, the average being seven minutes for each operation; but in practice it was usual to lift or lower a few partially at a time, and not the whole simultaneously.

The largest body of water run out of the Great Float at one time reduced it in depth 5 feet 3 inches; while the total quantity run off during the ten months the sluices were at work was, as nearly as could be ascertained, upwards of 8,000,000,000 gallons. Some difficulty was experienced in arriving at the quantity of water run off, owing chiefly to the long oscillating wave that came into play immediately the sluices were closed. The extreme length of the Float is nearly 2 miles; and when once the flow from it commenced, a current was established throughout the whole length. On one occasion some slight damage was caused to the Duke Street Bridge, situated about half-way up the Float (Plate 22), by two unmoored vessels in the west Float drifting down and fouling it. The sudden check in the flow, by the closing of the paddles, caused a rise in the water against the wall of the Float nearest the sluices of a foot or 15 inches above the previous level, producing the wave, which afterwards began to roll back to the further end of the Float, to return and roll back, again and again, with lessening volume, for upwards of an hour until entirely spent.

Records were kept of the duration of each sluicing operation, the time and tide of the day, the head of water, and other particulars, of which the following, for one set of springs in August, 1864, is an example—

RECORD of SLUICING OPERATIONS in August, 1864.

Day of the Month	16th.	17th.	18th.	19th.	20th.	22nd.	
Time of high water, as per Holden's Tide Table	hr. min. 10 9 A.M.	hr. min. 10 57 A.M.	hr. min. 11 42 A.M.	hr. min. 12 27 P.M.	hr. min. 1 10 P.M.	hr. min. 2 15 A.M.	
Height of tide above the Old Dock Sill, as per ditto	ft. in. 16 2	ft. in. 18 4	ft. in. 20 1	ft. in. 20 11	ft. in. 21 0	ft. in. 18 5	
Commenced opening the sluices	hr. min. 4 16 P.M.	hr. min. 4 52 P.M.	hr. min. 5 25 P.M.	hr. min. 6 15 P.M.	hr. min. 6 55 P.M.	hr. min. 8 22 A.M.	
Sluices closed	4 30 P.M.	5 14 P.M.	5 55 P.M.	6 42 P.M.	7 19 P.M.	8 42 A.M.	Total 137 min.
Duration of sluicing	14 min.	22 min.	30 min.	27 min.	24 min.	20 min.	
Level of water in the Great Float, above the Old Dock Sill, at the opening of sluices	ft. in. 16 0	ft. in. 17 6	ft. in. 18 6	ft. in. 18 3	ft. in. 18 3	ft. in. 16 10	
Ditto ditto, at the closing of sluices	13 1	13 3	13 3	13 3	13 2	13 0	
Depth of water run off	2 11	4 3	5 3	5 0	5 1	3 10	
Quantity of water run off, in gallons	109,060,000	158,916,000	196,308,000	186,960,000	190,076,000	143,336,000	Total 984,656,000
Level of water in the Low Water Basin, below the Old Dock Sill, at the opening of sluices	ft. in. 7 6	ft. in. 8 6	ft. in. 8 6	ft. in. 8 6	ft. in. 8 0	ft. in. 6 0	
NOTE.—The difference of level of the water in the Low Water Basin between the opening and closing of the sluices was almost inappreciable, and the attempt to record it was abandoned after the first few trials.							
Mean head of water	22 0	23 10	24 4	24 3	23 8	20 11	

	Below Old Dock Sill.	
	ft.	in.
The level of the bottom of the Low Water Basin prior to the commencement of the foregoing operations, taking the mean of all depths, was	20	3
Ditto ditto, after sluicing, ditto	20	7
Ditto ditto, prior to the sluicing, but exclusive of all depths in excess of 21 feet	19	5
Ditto ditto, after sluicing, ditto	19	8

The effect of the scour over the main portion of the Basin was tolerably equal. With the exception of the west end, where the bottom was swept out below the primary level, the final soundings showed no great amount of irregularity. At 1,350 feet from the head of the Basin, the difference between the deepest and shallowest sounding on the cross section was only 11 inches. At 1,150 feet, and also at 950 feet, the difference was 20 inches. At 750 feet it was 24 inches, and so on, with a gradually increasing difference as the head of the Basin was approached.

The observations made to ascertain the velocities of the several currents were, owing to surrounding difficulties, of an imperfect character. When the sluices were open from about three-fourths of their area to their fullest extent, the water rushed through the 30-feet chambers with a steep downward slope on the surface, and at a velocity varying from 12 to 20 miles and upwards an hour. On one occasion the speed of the stream in the Basin was taken on the surface, and also at certain depths below. Thus, at a point 1,500 feet from the head of the Basin, whilst the greatest velocity on the surface was found to be $3\frac{1}{4}$ knots per hour, two submerged meters, suspended at 9 inches and 5 feet respectively from the bottom (the depth of water being 10 feet), registered, the first, $\frac{1}{2}$ a knot, and the other one knot per hour only.

The calculated velocities through the sluices for the highest and lowest mean heads of water in the example quoted would be, for the 24 feet 4 inches head, 32 feet per second, or 21·8 miles per hour; and for the 20 feet 11 inches head, $29\frac{3}{4}$ feet per second, or 20·3 miles per hour; and assuming the sluices to be opened to their fullest extent, the speed of the current through the narrowest part of the Basin, at the end towards the river, would be at the rate of 5 miles for the greater, and 3·8 miles for the lesser head per hour.

It soon became evident, during these operations, that the running of the water was attended, not only with much inconvenience and hindrance to business, but with a considerable amount of danger. The rapid lowering of the water in the Great Float was highly objectionable. The Low Water Basin had to be cleared of vessels when the sluices were to be run, and delay arose at times on this account. The injury to the chambers showed the dangerous nature of the operations, for it indicated a tendency to destroy the foundations, and, by forming a sub-communication

between the Great Float and the Low Water Basin, to lead to the ultimate destruction of the works. The danger to be apprehended was shown early by the carrying away of the gates, and the uneasiness was not diminished when the sluicing had to be conducted in the dark mornings and evenings towards the fall of the year. The power let loose was of immense force, and a feeling arose that some great and sudden calamity, unforeseen and uncontrollable, might at any moment arise. Sluicing in the dark was therefore discontinued.

But notwithstanding the numerous drawbacks connected with the system, it will be apparent that the sluicing was capable of maintaining the Low Water Basin at its proper depth. In fact, it could do more than that, for at the time the operations commenced a deposit of 32 inches in thickness had accumulated; and at the end of ten months, when the scour had operated with more or less regularity through fifteen sets of spring tides, the deposit had been reduced to 14 inches, leading to the conclusion, that when the primary level had once been reached, a less amount of scouring power would have sufficed to maintain the required depth.

It was not, therefore, on the ground of inability to maintain it at its proper depth, that the closing of the Low Water Basin, and its conversion into a Wet Dock, was determined on. The principal reasons for adopting this course may be gathered from what has been already stated; and it was not until after much consideration by the Mersey Board, and long negotiations with Railway Companies and other public bodies interested in the welfare of Birkenhead, that the authority of Parliament for the abandonment of this great work was sought and obtained.

The preamble of the Act of 1866, after setting forth the section of the Act of 1858, authorizing the construction of the Low Water Basin, proceeds: "And whereas the said works have been completed and opened for public use, but the operation of the sluices constructed in accordance with the provisions of the said Act has been found to be dangerous to the stability of the works, and practically unsuited to the proper and efficient working of the Great Float and Low Water Basin for dock purposes, and it is therefore necessary that the use of such Basin for the purposes intended by the said Act should be abandoned, and it is expedient in order to utilize as far as possible the large amount of money already expended upon the works, that the said Low Water Basin should be converted into a Wet Dock, so as to be used in connection with the Great Float, by the construction of a sea wall at the eastern extremity of such Basin."

No specific time is mentioned for carrying out the work. Meanwhile the Basin is gradually silting up. Soundings have been

taken since the close of the sluicing operations, and the last, in November, 1867, gave an average depth over the Basin of 11 feet below the datum. The average of all depths in November, 1864, when the sluicing ceased, was 20 feet 8 inches, and the latest soundings show that in three years the deposit has increased 9 feet 8 inches, or at the rate of nearly 39 inches per annum, being an average accumulation of about $\frac{3}{4}$ of an inch, or 1,387 cubic yards, per week.

The total capital expenditure on the Low Water Basin, including the sluicing appliances, the 50-feet lock, and the landing stage, was £470,252. The estimate for enclosing the Basin and forming it into a Wet Dock is £122,000.

At the commencement of this description it was remarked, when alluding to the special advantages offered by Birkenhead as a situation for docks, that a greater depth of water, and a better shelter from prevailing winds, were two material points strongly in its favour, when compared with the shallow and exposed shore on the Liverpool side.

With regard to the winds, the following summary of the records kept at the Liverpool Observatory during the twelve years ending 1863 will perhaps be of interest:—

Number of days during which the wind was north-easterly. Mean of 12 years	51·4	
Ditto ditto south-easterly	116·0	
		167·4
Ditto ditto north-westerly	112·6	
Ditto ditto south-westerly	84·5	
		197·1
Calm days	..	0·8
		365·3

The proportion, therefore, is in the ratio of about five days easterly winds to six days west. The records further show, that the stormy weather is entirely from the two westerly quarters, and that all winds having a mean hourly velocity of 15 miles and upwards an hour are from these quarters.

But since 1844, when this point was raised in favour of Birkenhead, the Northern Docks at Liverpool have been constructed, and experience has shown that the advantages attributed to the prevailing winds are not of the importance they were formerly supposed to be. Ships are docked and undocked in all weathers at Liverpool, and it has been clearly established, that they can be taken into dock whenever it is safe for them to leave their anchorage in the river.

With reference to the depth of water, the following Tables give the results of two sets of soundings, on three lines of sections, taken across the river between Liverpool and Birkenhead; the first in 1822, and the second in 1857.

No. 1.

	Distance in Feet from the line or Face of River Wall.	Soundings below the level of Old Dock Sill.					
		Liverpool.		Birkenhead.			
		ft.	in.	ft.	in.	ft.	in.
Section line from the north end of the Birkenhead river wall at Seacombe to near the north end of the Prince's Dock at Liverpool, taken in 1822.	50	19	3	7	8	11	7 Excess of depth in favour of Liverpool.
	100	27	0	8	6	18	6 Ditto.
	200	36	5	11	8	24	9 Ditto.
	500	40	6	28	6	12	0 Ditto.
	1,000	50	6	45	0	5	6 Ditto.
Ditto, ditto, taken in 1857.	50	19	3	9	0	10	3 Ditto.
	100	31	6	10	0	21	6 Ditto.
	200	39	5	14	0	25	5 Ditto.
	500	46	3	30	0	16	3 Ditto.
	1,000	55	0	54	0	1	0 Ditto.

No. 2.

	Distance in Feet from the line or Face of River Wall.	Soundings below the level of Old Dock Sill.					
		Liverpool.		Birkenhead.			
		ft.	in.	ft.	in.	ft.	in.
Section line from about the centre of the Birkenhead river wall to the south end of the Prince's Dock, Liverpool, taken in 1822.	50	9	0	19	6	10	6 Excess of depth in favour of Birkenhead.
	100	11	6	21	6	10	0 Ditto.
	200	15	0	26	6	11	6 Ditto.
	500	37	6	36	0	1	6 Excess of depth in favour of Liverpool.
	1,000	51	0	49	0	2	0 Ditto.
Ditto, ditto, taken in 1857.	50	9	0	13	6	4	6 Excess of depth in favour of Birkenhead.
	100	29	0	15	6	13	6 Excess of depth in favour of Liverpool.
	200	48	0	18	0	30	0 Ditto.
	500	48	6	31	9	16	9 Ditto.
	1,000	59	0	48	0	11	0 Ditto.

No. 3.

	Distance in Feet from the line or Face of River Wall.	Soundings below the level of Old Dock Sill.					
		Liverpool.		Birkenhead.			
		ft.	in.	ft.	in.	ft.	in.
Section line from near Morpeth Dock to George's Baths, taken in 1822.	50	4	0	26	5	22	5 Excess of depth in favour of Birkenhead.
	100	5	6	30	0	24	6 Ditto.
	200	9	2	36	0	26	10 Ditto.
	500	23	0	42	0	19	0 Ditto.
	1,000	52	0	52	6	0	6 Ditto.
Ditto, ditto, taken in 1857.	50	10	0	3	0	7	0 Excess of depth in favour of Liverpool.
	100	13	6	5	6	8	0 Ditto.
	200	18	9	19	6	0	9 Excess of depth in favour of Birkenhead.
	500	44	9	39	0	5	9 Excess of depth in favour of Liverpool.
	1,000	63	6	50	0	13	6 Ditto.

An inspection of these Tables, and of the Drawings (Plate 26), on which a third section, taken about the year 1843, is also laid down, will show the changes which have taken place in the bed of the river, immediately opposite the Birkenhead Docks, between Woodside and Seacombe, and it will be seen that the advantage in point of depth is somewhat on the Liverpool side.

The Paper is accompanied by a series of reduced Drawings, from which Plates 22 to 26 inclusive, have been compiled.

It was announced that the Discussion upon this Paper, which was commenced, would be resumed at the first Meeting of the Institution after the recess; and that the Report of the Discussion would be deferred until it was concluded.

No. 1,225.—"On the Present State of Knowledge as to the Strength and Resistance of Materials."[1] By Jules Gaudard, Civil Engineer, Lausanne. (Translated from the French by William Pole, F.R.S., M. Inst. C.E.)

Introductory Remarks.

1. The theory of the strength and resistance of materials is closely connected with that of molecular mechanics. The latter science, however, is much more extensive, and affects many other problems than those of the practical engineer: it has been the subject of learned researches, often difficult to understand, and still more to analyse or criticise in a memoir of limited extent. Moreover, the strength of materials being a branch altogether of practical application, requires only to borrow from scientific theories the principles on which to base rules of construction, simple enough to be of general application, and yet sufficiently exact to be used with confidence.

The formulæ of strength bring into view, on the one hand, the destructive action of external forces, and, on the other hand, the resisting molecular actions of the material.

External forces are of two kinds: one kind comprises elements directly given, such, for example, as weights; the other kind consists of reactions, functions of given forces. In certain cases these reactions may easily be found by the science of statics alone (as, for example, in the case of a beam placed on two supports). In other cases they will depend on the changes of form of the solid; it is this, for example, which causes the difficulty of calculation in arches and in continuous beams of several spans. Or, lastly, it may happen that the body in question may not be in a state of equilibrium, but that its particles may oscillate under variable dynamic influences or forces of inertia: this is the case of concussions, vibrations, &c.

These various external forces being determined, it will easily be seen whether they tend to cause certain parts of the solid to elongate, or to shorten, or to shear, or to turn round certain axes. These

[1] This Paper was necessarily read in abstract, and is now printed *in extenso*. with a view to its discussion early next Session.

various effects, extension, compression, sliding, torsion, flexure, may further manifest themselves separately or may combine with each other.

Under the action of these forces, the body will necessarily be changed in form; for solids perfectly rigid are only pure abstractions. The study of these changes of form constitutes the object of the theory of elasticity. The study of strength or resistance has to do with the power which the solid, according to its physical constitution, possesses to maintain, if not its form, at least the cohesion of its parts.

For the constructive engineer the question of resistance to rupture is of capital importance. The elastic change of form interests him less directly, because he knows beforehand that this change is generally very small, and presents no great inconvenience. It often happens, however, that the two questions are connected together; for example, in the case already cited, where the change of form of the body influences the reaction which it receives from its external supports. It may happen, also, that a change of form may present in itself a direct practical interest: thus in the testing of a bridge, if the observed deflection agrees with that predicted by the calculation of the elasticity, it will be inferred that the beams do not possess any hidden defect capable of producing an abnormal deflection. The changes of form may also exert a notable influence on the strength of constructions where different materials are combined together.

Extension.

2. Molecular action is a force internal, or reciprocal, which opposes indefinitely the approximation of two particles, but only opposes their separation up to a certain limit. This limit being attained, the two particles find themselves suddenly withdrawn from their sphere of mutual action, and rupture takes place.

According to this idea a fibre or thread of particles being subjected to tension, the force producing rupture may be measured, and this force will vary with the substance. In this elementary case, so simple in appearance, the question arises, whether a particle extends its attractive action beyond the particle immediately adjoining it on either side? If this were so there would be differences of condition between the ends and the middle of the fibre, and we ought to be able to designate beforehand the points of rupture. But we do not know that these points are determined by any other laws than the mere caprice of the specimen, and we assume, that, for a thread of an absolutely theoretical regularity, the rupture may take place at every point at the same instant.

If we take a material rod of finite thickness, the phenomenon becomes more complicated; for the particles now undergo displace-

ments, not only longitudinally but also transversely. This is very obvious with a viscous matter, which diminishes in thickness as it is increased in length; but as everything is continuous in nature, viscous or pasty matters of all degrees mark the transition from liquids to solids, and these latter ought to preserve in a faint degree the same physical properties. This is, moreover, a fact which the experiments of M. Tresca, upon the flow of solids, have shown in a striking manner.

Here we already find ourselves in the presence of an obscure phenomenon of molecular mechanics. In considering, however, the strength of materials, we evade the difficulty, as we are content to assimilate the compact rod to the assemblage of its elementary fibres, close but unconnected, and thus exercising no mutual lateral actions. This voluntary error is excused, not only for the sake of simplification, but also because it appears to be of a kind which may be neglected in the presence of certain accidental irregularities which we provide for, as best we can, by modifying in the particular case the value of the coefficients. Thus, for example, iron wire, owing to its peculiar mode of manufacture by drawing (écrouissage), is relatively stronger than iron in thick bars.

It is admitted, then, that the tensile stress[1] N which a rod can sustain is proportional to its section ω, that is, $N = R\,\omega$, where R designates the resistance to rupture per superficial unit of the section.

The phenomenon of change of form is successive and continuous, which distinguishes it from the instantaneous phenomenon called rupture. It may be followed by the eye, by observing the elongations δ of a unit of length of the rod under increasing loads N. The curve of which δ is the ordinate, and $N\left(\text{or } \frac{N}{\omega}\right)$ the abscissa is not a straight line; its differential coefficient increases at first very slowly, and then more rapidly as it approaches rupture. Under moderate loads, however, we admit the proportionality of δ to N, and we always assimilate the rod whose section is ω to a bundle of independent fibres placed in juxtaposition. Hence the formula $N = E\,\omega\,\delta$, where E is the modulus of elasticity. If E varies in the section, we write $N = \delta \int E\,d\omega$. The factor $\int E\,\delta\,\omega$ is called the *longitudinal spring* (ressort longitudinal). The resultant N of the tensions is understood to pass through the centre of elasticity.

[1] The translator has thought it right to follow in this translation the nomenclature adopted by Rankine and other modern English writers on Mechanics. The word "stress" is used by them to denote "forces exerted between contiguous bodies or parts of a body, and which are distributed over the surface of contact of the masses between which they act." The word "strain," which has long been used in Engineering Mechanics to denote either this or a very analogous meaning, appears to have been given, by these writers, a new and different interpretation. *Vide* Rankine, "Applied Mechanics," Art. 86 and 242.

3. Great importance has been attached, as a matter of principle, to the vague idea of the limit of elasticity. Below this limit the elongation δ would be proportional to the force N, according to the preceding formula, and it would vanish by the removal of the force, the rod then resuming its primitive length. It appears to be shown that it is necessary to distinguish two kinds of elongation, one permanent—a kind of wire-drawing, very inconsiderable at the commencement, but increasing rapidly and degenerating into enervation under considerable loads;—the other elastic, that is, obeying the law of proportionality to the force and vanishing therewith. The permanent elongation would seem to present the character of not being renewed by the return of the same force or of smaller forces, in which case the law of elastic pulsation obtains freely. The limit of elasticity would be practically the point below which the permanent elongation is not appreciable.

These hypotheses, however, are open to doubt. Certain facts seem to establish that time intervenes as an enervating cause, by giving permanence to elongations which are at first elastic, and by consequently diminishing the vigour of the material to react against derangements. It has been remarked, that fibrous iron tends to acquire a granulated or crystalline texture by long-continued concussions. It might thus be apprehended that an iron beam which now is amply strong, might, even though protected from all oxidation, break fatally some day by the sole effect of the repeated action, or long continuance of the load. If this is so, the theory of resistance ought, perhaps, to be changed in character; instead of saying vaguely that a certain material, subjected to certain work, presents guarantees of safety, it ought to announce for how long a period, or how many times, it will support the test with impunity. This doctrine of instability appears but too well supported by analogy; everything is stamped with the seal of destruction.

For the case of great stresses passing beyond the conventional limit of elasticity, Barré de Saint Venant has proposed to substitute, for the law $\frac{N}{\omega} = E\delta$, the expression $\frac{N}{\omega} = E\left[1-(1-\delta)^m\right]$, m being a number > 1.

Compression.

4. The resistance offered by two particles when caused to approach each other is indefinite, and a solid or even a liquid may support any pressure, distributed uniformly over its circumference in such manner that no particle can escape by sliding away. For example, it would be impossible to succeed in crushing the water contained in a hydraulic press.

What then is crushing? This word is applied to solids pressed irregularly upon different faces or portions of their external contour. The form ordinarily presented is that of prisms pressed only on their bases. Such a solid shortens, but its density does not augment in an equal proportion, because certain particles near the lateral contour flow to the exterior. The body swells, principally in the middle of its length; sometimes it exfoliates in filaments which detach themselves and fall away on various sides. These effects constitute crushing. They are due to internal sliding actions, calling into play the resistance of certain particles to lateral disjunction.

In prisms of very elongated form, the phenomenon is modified by the tendency of the middle of the rod to deviate altogether, from its original straight form, under the most imperceptible cause; thus flexure arises, and the moment of resistance of the rod becomes of more importance than the area of its section. Thus the case of a pillar pressed upon its bases is very imperfectly understood. We are almost reduced to the application of formulæ purely empirical, which aim rather at conforming to observed facts than at explaining them. They are valuable as expressing the results of numerous observations, as guides for ordinary practice, and as steps towards the discovery of laws. But the ideas latent in them are often masked by the divergent circumstances of the experiments, and the functions assume different forms under the hands of different observers. Generally, in practical construction, we apply to compressed prisms the same formulæ, $N = R' \omega = E \omega \delta$, as for rods in tension, when the length does not exceed, for example, ten times the thickness. For longer lengths recourse is had to experimental formulæ, or to the reduction, more or less arbitrarily, of the coefficient R' of the pressure admissible per unit of surface. M. Love has reduced into formulæ the experiments of Hodgkinson on long columns.

5. Researches have been made on the lateral bulging out of a compressed prism, or the analogous contraction of a stretched rod. For an isotropic body, that is, one which has a similar texture in every direction, Barré de St. Venant shows that a bulging $\frac{\delta}{4}$ of the transverse lineal dimensions corresponds to a proportional shortening $\delta = \frac{R}{E}$, of the length of the prism. In this way the unit of primitive volume will have become

$$= (1 - \delta)\left(1 + \frac{\delta}{4}\right)^2 = \text{sensibly } 1 - \frac{\delta}{2}.$$

Wertheim arrived at $\frac{\delta}{3}$ for the contraction of the volume instead

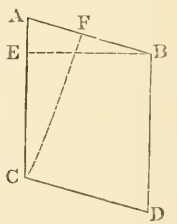
of $\frac{\delta}{2}$. It must, however, be stated that the isotropic condition is merely a theoretical abstraction.

If it is true that compression is only dangerous on account of the lateral bulging which it causes, we may conclude from what precedes, that a prism may carry four times more by compression than by extension, provided that, by its short length or otherwise, it be preserved from all lateral bending.[1]

Sliding (Glissement).

6. Two portions of a solid contiguous to a common section, tend to slide one upon another, when they are acted upon by a relative shearing force parallel to the section. The corresponding change of form is no longer a simple translation, but is an angular deformation.[2] Having given a small parallelopiped, of which the base, at first rectangular, is deformed [1] into an oblique parallelogram A B D C, Fig. 1; then letting fall B E perpendicular to A C, we may say that the face projected on B D has moved before A C by the relative quantity $\frac{A E}{A B}$, and this motion is the same as that $\frac{A F}{A C}$ of C D before A B. In other words, the sliding between two parallel and neighbouring faces inclines their primitive common normal, and is measured by the projection on one of them, of the unit of length applied on the normal which has deviated. It is the small cosine acquired by the deformed angle which was originally a right angle.

Fig. 1.



This principal sliding g is in the same direction as the projection of the deviated normal. We may estimate first the component slidings g' and g'' parallel to the directions of two rectangular axes traced beforehand on the section; then the principal sliding will be $g = \sqrt{g'^2 + g''^2}$.

7. The sliding action causes stretching of the fibres, for in every rectangle transformed into an oblique parallelogram one diagonal will be lengthened, the other diagonal will be contracted. The greatest stretching, and also the greatest contraction, per unit of

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[1] This conclusion, however, requires considerable modification in practice.—Tr

[2] I have ventured to use these words as simple and expressive equivalents for the French *déformation*, *déformer*, &c.—Tr.

length, will have the value of the half sliding $\frac{g}{2}$, and will be manifested in directions drawn at 45° to the face in question.

8. Up to a certain limit the sliding g is proportional to the shearing force F applied to the face whose area is ω. The change of form is thus defined by the formula $F = G\,g\,\omega$; the coefficient G bears the name of the *modulus of transverse elasticity;* it will be constant like E within the limit of elasticity. If this modulus varies in different parts of the area ω, we write $F = g \int G\,d\,\omega$; and $\int G\,d\,\omega$ is what is called the *transverse spring.* If T represents the tangential resistance to sliding per unit of surface, we have $F = T\,\omega$. These formulæ only apply to a section of finite area ω, while this section is compelled to continue plane; for in the case where it is free to bend, there will arise an unequal distribution of the sliding in the various parts.

An isotropic substance, capable of supporting a longitudinal tension R per unit of surface, which extends it a quantity $\frac{R}{E}$, may (Art. 7) resist a sliding of double this extent $= 2\frac{R}{E}$, or a tangential stress $T = 2\frac{G\,R}{E}$. Barré de St. Venant having been led to the ratio $\frac{G}{E} = \frac{2}{5}$ between the moduli of transverse and longitudinal elasticity, we have $\frac{T}{R} = \frac{4}{5}$ for the ratio of the tangential and longitudinal stresses producing equal fatigue.

Texture of Bodies.

9. In the absence of knowledge as to the irregularities which may exist in various parts of the same body, it is customary to consider the materials employed in construction as homogeneous. In some cases, however, we are aware of the irregularity; for example, we know that in cast iron, the external skin is of a closer texture than the internal mass, and we may take account of this by causing the coefficients E, G, R, T, to vary in different points of the section of the solid considered.

As to the texture at any given point, there are two ordinary cases:—

1. Amorphous or granular bodies, in which we assume a similar texture in all directions.

2. Fibrous substances; in which the texture is uniform in all

the transverse directions perpendicular to the fibres, but is quite different in the directions of the fibres themselves. The coefficients which characterise this texture vary therefore in different directions like the radii of an ellipsoid of revolution. Experimental data, to be complete, ought to furnish the various relative coefficients for the principal directions, which ought to be applied, sometimes one and sometimes the other, according to circumstances.

We know, for example, with fir wood, how much easier it is to cause the fibres to slide upon each other, than to shear them transversely, and how much easier to separate them laterally than to break them by longitudinal tension.

If, in some cases, we admit an unequal texture in three rectangular directions, the tensions corresponding to different positions will be represented by the radii of an ellipsoid with three unequal axes.

Crystalline bodies present faces of cleavage which have little adherence, however hard may be the crystals themselves. This molecular constitution is too complicated to enter into the formulæ of strength, and therefore we should treat such substances as amorphous, attributing to them coefficients with a mean practical value.

Limits of Safety.

10. Experience furnishes the values of the coefficients R and T, which produce rupture by tension or fracture by shearing (*cisaillement*). In permanent constructions it is necessary to keep much within these limiting values. We therefore choose, somewhat arbitrarily, the limits of strength about $\frac{1}{10}$ for substances which are but slightly homogeneous (such as wood or stone), and from $\frac{1}{4}$ to $\frac{1}{6}$ for metals. The great difference between the coefficient admitted in practice, and that which produces rupture, is demanded not only by what has been said concerning the limit of elasticity, but also by the possibility of concussions or unknown vibrations, by the thousand small hidden defects of the substances, and finally in order to cover the defects of the theory itself.

The immense variety of nature renders the task of experimenters very indefinite. Every isolated trial has only an absolute value for specimens identical with that tried. The discussion is delicate, and it is only possible to give approximate mean values as general results. The origin, the dimensions, the mode of manufacture, the annealing, the age, the humidity, and many other circumstances influence the strength. The labours of Hodgkinson, Fairbairn, Rondelet, Morin, and other scientific men, have accumulated a great number of useful data regarding the principal materials of

construction, and yet there remains much to be done in this vast field of practical investigation.

The imperfections of theory require also reserve in the choice of the limits of safety. Certain errors act in a favourable direction; but in ignorance of this it is often necessary to provide against them, by attributing to them an unfavourable effect. The improvement of the science ought to tend to realize an exact determination of the conditions of strength in all the parts of a work; for example, the most economical framework for a given structure will be that which would fail simultaneously in all its bars, when the strain is augmented to rupture. The scale of security (or the suitable interval between the practical coefficient and that of rupture) will always have a character more or less arbitrary, because it will be always more prudent, but more costly, to have a smaller than a greater stress upon the material.

False hypotheses arise either from ignorance of the laws of the material, or from the conditions differing too much from practice, or from the obligation to simplify the calculation, which otherwise might be inextricable. It is thus that in most cases we only consider the states of statical equilibrium, omitting the consideration of vibrations or dynamical effects. In a continuous beam of many spans we must begin upon the hypothesis of the invariability of the supports, although we cannot be unaware that a very slight error of level may overthrow all our calculations. We may also instance the shearing of a rivet: the formula assumes an equal distribution of the shearing force on all the elements to be sheared, in such a manner that the disjunction may take place everywhere at the same instant; and yet in the reality the edge attacked will be crushed before the opposite edge has moved.

Torsion.

11. When a cylinder is twisted by a couple whose moment is $= \mu$, and whose plane is perpendicular to the axis of the cylinder, every transverse section turns, relatively to its adjoining section, round the axis passing through their centres of elasticity. If φ is the arc of torsion (relatively to the radius) per unit of length of the cylinder, and if ω is the sectional area, then an element $d\omega$ of this area, situated at a distance r from the axis, will suffer a stress $G \varphi r \, d\omega$ in the direction of the tangent to the circle of radius r (G being the modulus of transverse elasticity or elasticity by sliding). The aggregate of these stresses, on the section ω, will be equal to a couple whose moment is $= \mu = \varphi \int G r^2 \, d\omega$. In the case of a homogeneous material, the moment of torsibility $\int G r^2 \, d\omega$, may be written $G \int r^2 \, d\omega$, or G J, where J is the polar moment of inertia $\int r^2 \, d\omega$ of the section referred to its centre of gravity. The

LOW WATER BASIN, BIRKENHEAD.

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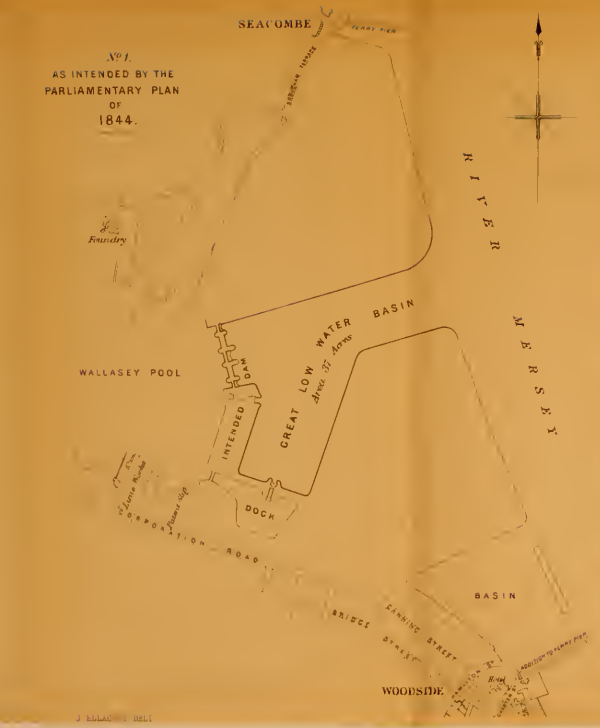
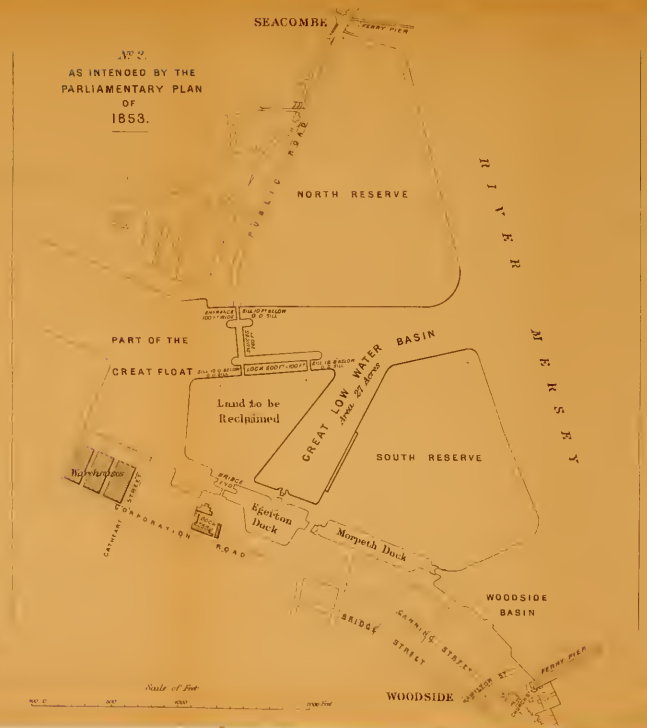
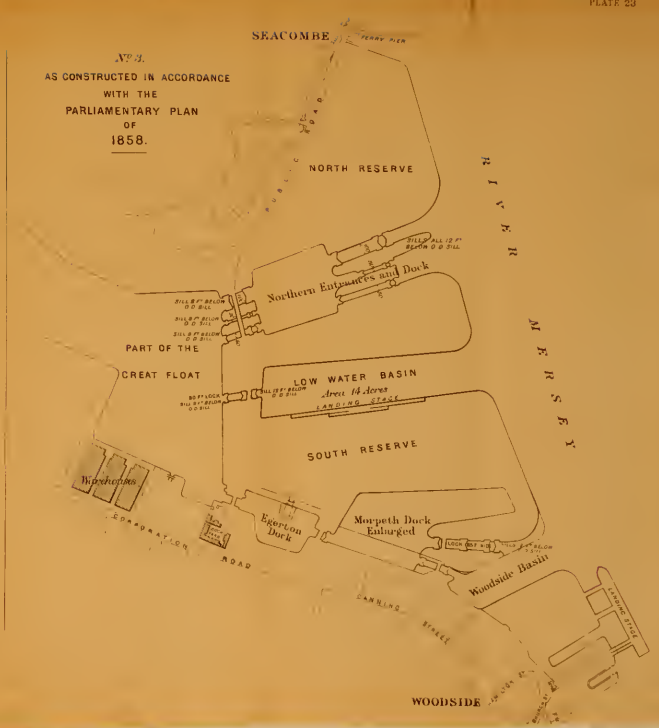
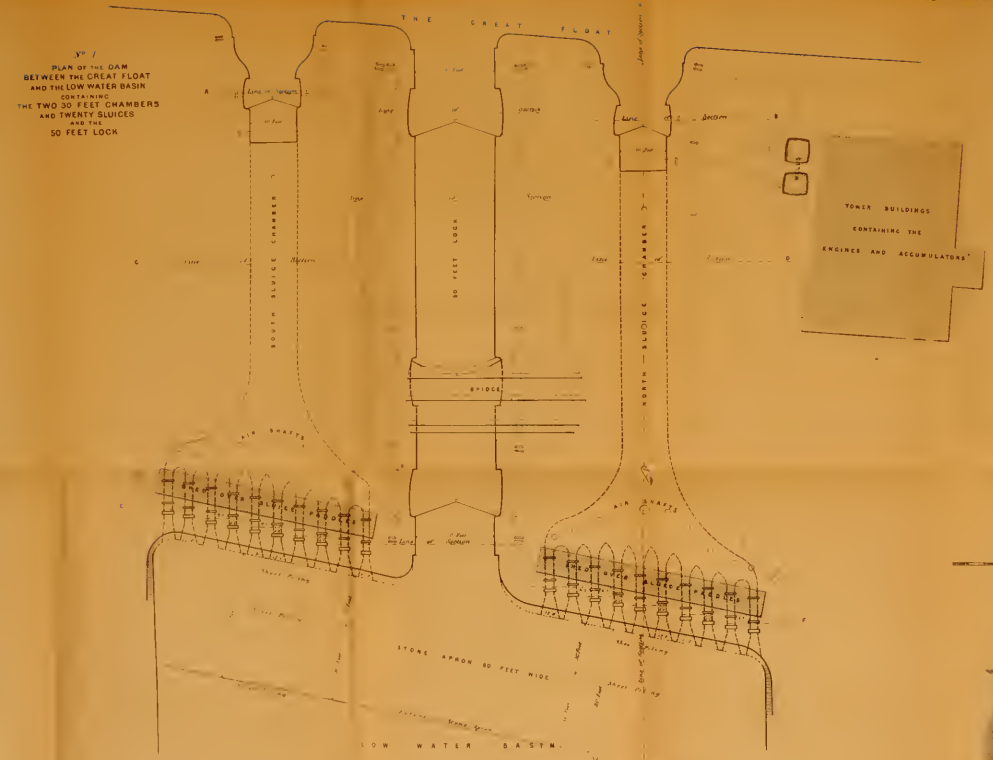


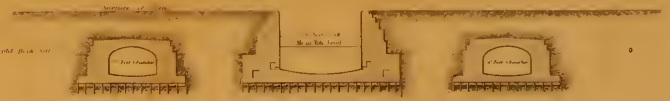


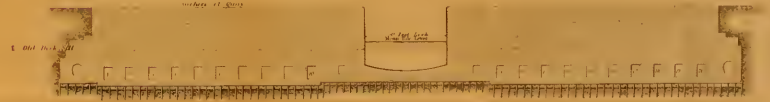




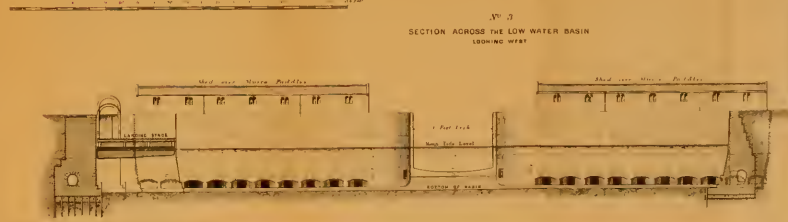
N° 1
PLAN OF THE DAM
BETWEEN THE GREAT FLOAT
AND THE LOW WATER BASIN
CONTAINING
THE TWO 30 FEET CHAMBERS
AND TWENTY SLUICES
AND THE
50 FEET LOCK

SECTION ON LINE A B


SECTION ON LINE C D


SECTION ON LINE E F

N°
SECTIONS
THROUGH THE
CHAMBERS LOCK AND SLUICES
IN THE DAM
BETWEEN THE GREAT FLOAT
AND THE
LOW WATER BASIN

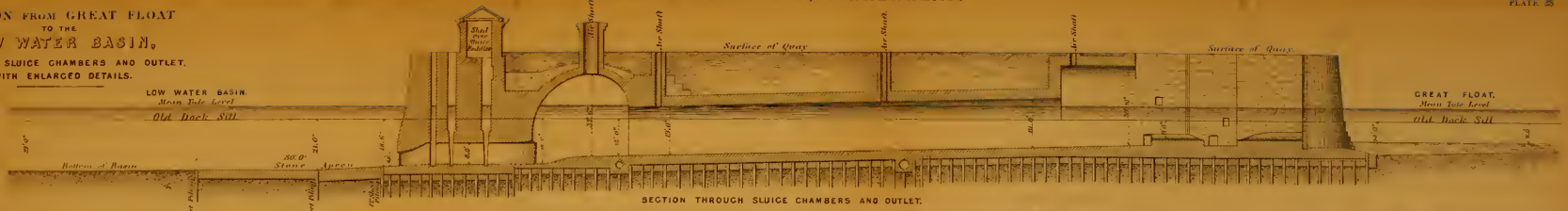


N° 3
SECTION ACROSS THE LOW WATER BASIN
LOOKING WEST

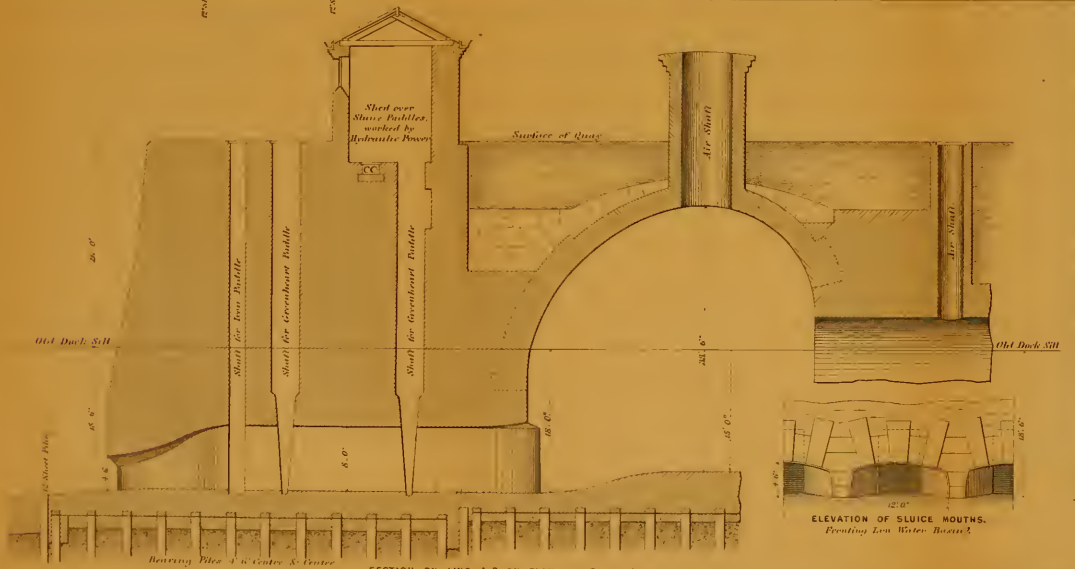
LOW WATER BASIN, BIRKENHEAD.

SECTION FROM GREAT FLOAT TO THE LOW WATER BASIN.

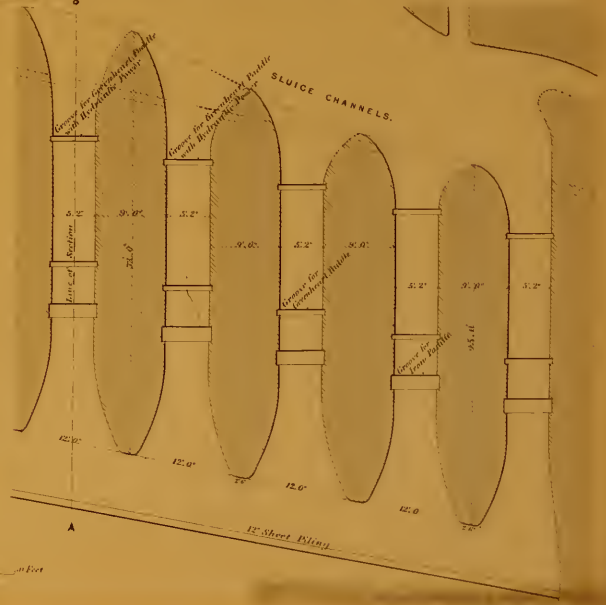
THROUGH THE SLUICE CHAMBERS AND OUTLET.
WITH ENLARGED DETAILS.



SECTION THROUGH SLUICE CHAMBERS AND OUTLET.


Shed over Sluice Paddles worked by Hydraulic Power
Air Shaft
Surface of Quay
Old Dock Sill
Shaft for Low Paddle
Shaft for Greenheart Paddle
Shaft for Greenheart Paddle
Bearing Piles 3' 6" Centre to Centre
SECTION ON LINE A B ON PLAN.

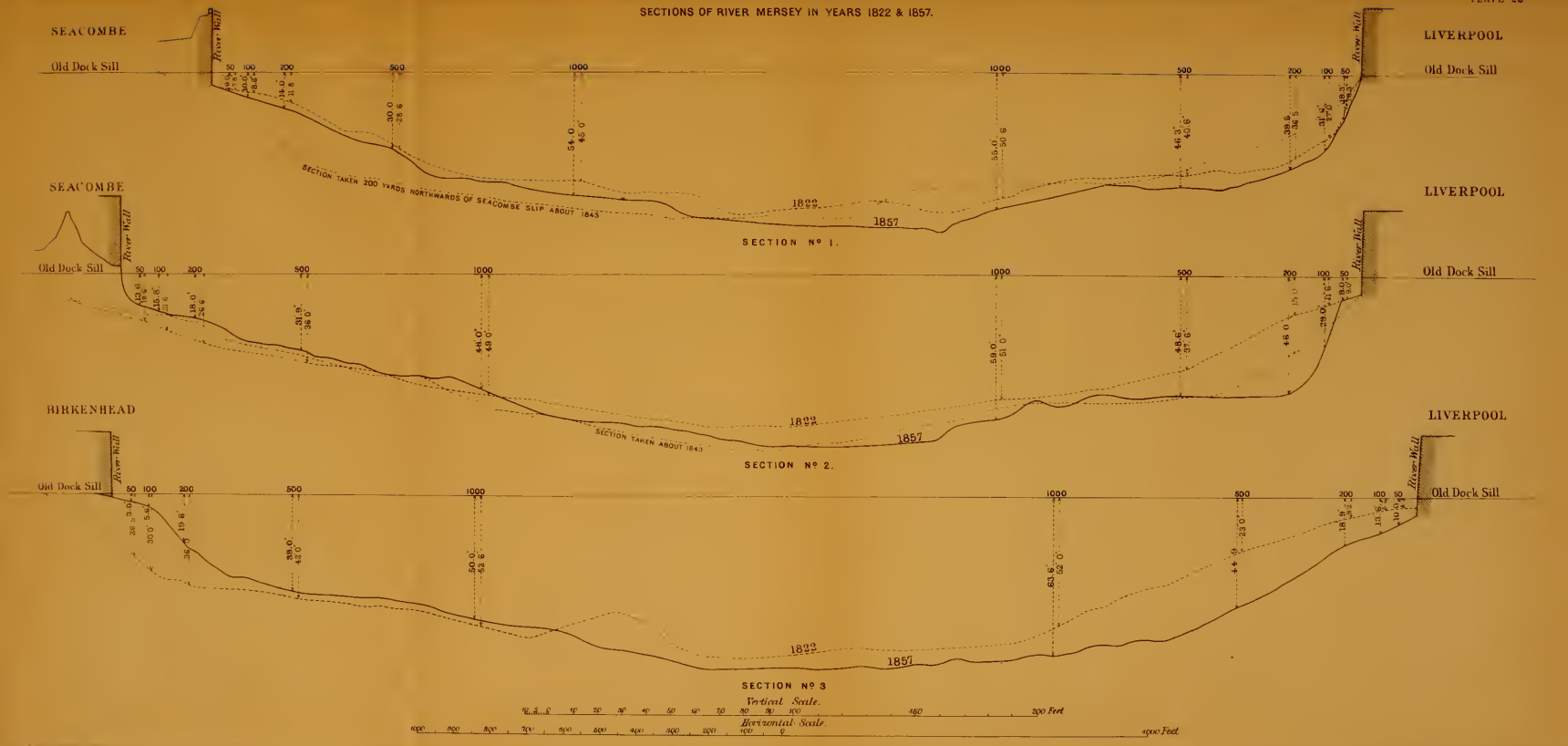
ELEVATION OF SLUICE MOUTHS.
Fronting Low Water Basin.



LOW WATER BASIN, BIRKENHEAD.

SECTIONS OF RIVER MERSEY IN YEARS 1822 & 1857.

PLATE 26



shearing stress T, per superficial unit, at a point distant r from the axis, will be $T = \frac{\mu r}{J}$. The fibre passing through this point will be bent into a spiral, whose tangent of inclination, relatively to the axis, is $r\varphi = \frac{\mu r}{GJ} = \frac{T}{G}$. The maximum T_1 of the stress T will be at the circumference. Thus the section being a circle of a radius r_1, we have $T_1 = G g_1 = \frac{\mu r_1}{J} = \frac{2\mu}{\pi r_1^3}$; g_1 being the maximum sliding.

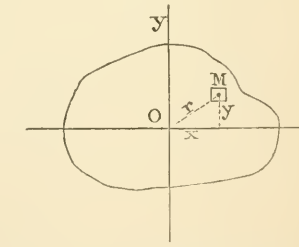
The relative sliding of two transverse sections (Art. 7) involves an equal sliding of the fibres one upon another, and also an extension or compression of the spiral lines inclined at 45° to the axis of torsion.

The moment of torsion expressed by $G\varphi J$ is exact for slight deformations of circular cylinders, or for very short prisms whose sections would be compelled to continue plane. But it would not apply to prisms whose transverse sections are free and not circular, for these sections give way and bend instead of remaining flat. In such a case the moment of torsion is less than $G\varphi J$, and in order to determine it recourse must be had to the theory of M. Barré de St. Venant, now about to be explained.

12. Any element of the lateral free surface is carried along by the interior parallel and contiguous layer, without any relative sliding; for it would require an external tangential force, such as friction, to oblige the element to slide. Consequently the transverse sections of the prisms bend, in such a way as always to cut normally the lateral twisted surface. It is thus necessary to take account of this deformation, in estimating the real slidings tending to shear the fibres.

Trace (Fig. 2) two rectangular axes O x, O y, in the primitive plane section, and passing through the centre of elasticity O (axis of torsion). An element M, whose distance from O is $r = \sqrt{x^2 + y^2}$, will have left the plane of the axes after the torsion, and we will call z its distance outside this plane. If we neglect this distance z, the inclination taken by the twisted fibre passing through M, in virtue of the arc of torsion φ, will produce simply a sliding $r\varphi$ perpendicular to the radius r; this sliding may be decomposed into its projections;—$y\varphi$ in the direction of the

Fig. 2.



abscissa x, and $x\varphi$ in that of the ordinate y. If, now, we suppose that the fibre has remained vertical, in order only to occupy ourselves with the displacement z, the small inclination $\frac{dz}{dx}$ will measure the sliding parallel to Ox, and $\frac{dz}{dy}$ that parallel to Oy. The composition gives $g' = \frac{dz}{dx} - y\varphi$ for the effective sliding in the direction of x, and $g'' = \frac{dz}{dy} + x\varphi$ for that in the direction of y. The principal sliding will be the resultant $g = \sqrt{g'^2 + g''^2}$.

Differentiating g' in respect to y alone, and g'' in respect to x, and reducing, we obtain the relation $\frac{dg''}{dx} - \frac{dg'}{dy} = 2\varphi$.

13. The slidings g' and g'' are not only the slidings between transverse sections, which tend to shear the fibres. There are also (Art. 6) the slidings of the fibre, relatively to its neighbours, following the small longitudinal faces, parallel respectively to x and y. If then the extreme bases of the fibre do not support the normal pressures, if the weight be neglected, and if the texture is similar in all the transverse directions, the longitudinal equilibrium of the fibre will require this general indefinite condition $\frac{dg'}{dx} + \frac{dg''}{dy} = 0$. According to the above given values of g' and g'' this condition is expressed by the equation of the partial differential coefficients of the second order

$$\frac{d^2z}{dx^2} + \frac{d^2z}{dy^2} = 0. \qquad [1]$$

Further, there exists a special condition for the points of contour of the section, *i. e.*, the condition of normality between the section and the lateral faces of the prism. It is necessary that the principal sliding shall become, at these points, tangential to the contour, which is expressed by $\frac{g''}{g'}$

$$\text{or} \quad \frac{\frac{dz}{dy} + x\varphi}{\frac{dz}{dx} - y\varphi} = \frac{dy}{dx}. \qquad [2]$$

Under the slidings g' and g'' the elements $d\omega$ of the transverse sections experience tangential or shearing actions, equal to

$G\left(\frac{dz}{dx} - y\varphi\right) d\omega$ in the direction x and equal to $G\left(\frac{dz}{dy} + x\varphi\right) d\omega$ in the direction of y. These actions constitute, in the aggregate, a couple which resists the given moment μ of the external forces tending to twist the prism. We have thus

$$\mu = G \int_0^{\omega} \left[\left(\frac{dz}{dy} + x\varphi\right) x - \left(\frac{dz}{dx} - y\varphi\right) y\right] d\omega.$$

This expression determines the torsion φ; we find $\frac{dz}{dx}$ and $\frac{dz}{dy}$ by integrating equation [1] with the condition expressed by equation [2], adapted particularly to the given contour of the base of the prism.

14. As the direct application of the above presents great difficulties, M. de S. Venant has contrived an expedient, which consists in assuming *à priori* the deformation z; then the contour of the base of the prism becomes the unknown quantity, and it is endeavoured, by the choice of z, to arrive at forms of contours which may be met with in practice. We need only give some of the most remarkable results.

For the *cylinder with circular base*, $x^2 + y^2 = a^2$ (a = radius), we find $z = 0$, *i. e.* the sections continue plane. The moment of torsion has the value $\mu = G\varphi \int (x^2 + y^2)\, dx = G\varphi J$; $= \frac{\pi}{2} G\varphi a^4$. The greatest shearing stress is produced at the circumference, and has the value $T = G a \varphi = \frac{2\mu}{\pi a^3}$ per unit of surface. The circular section is the best of all solid forms for the resistance to torsion.

In the *elliptic cylinder*, $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$ (the ellipse having axes $= 2a$ and $2b$) the sections bend into hyperbolic paraboloids given by $z = \frac{b^2 - a^2}{a^2 + b^2} \varphi x y$. The axes of the ellipse preserve their rectilinear direction; but hollows are produced in two opposite quadrants, and projections in the others. The moment of torsion is $\mu = \frac{a^3 b^3 \pi G \varphi}{a^2 + b^2}$. The principal sliding $g = \frac{2\varphi\sqrt{a^4 y^2 + b^4 x^2}}{a^2 + b^2}$ increases from the centre to the circumference; its greatest value takes place, not on the fibres farthest removed from the centre (axis of torsion), but at the extremities of the minor axis of

the ellipse (points when $x = o, y = \pm b$). The greatest shearing stress is consequently

$$T = \frac{2\,G\,a^2\,b\,\varphi}{a^2 + b^2} = \frac{2\,\mu}{\pi\,a\,b^2}.$$

In the *equilateral triangular prism*, whose side = a, the maximum sliding is produced at the middle of the sides, and the equation of resistance to shearing is $T = \frac{\sqrt{3}}{4}\,G\,a\,\varphi = 20\,\frac{\mu}{a^3}$. The moment of torsion $\mu = \frac{\sqrt{3}}{80}\,G\,a^4\,\varphi$ is only $\frac{3}{5}$ of the value $G\,\varphi\,J$ which it would have on the hypothesis of sections continuing plane.

15. In the *rectangular prism*, whose sides are a and b, the solution is very complicated. The moment of torsion is expressed thus:

$$\mu = G\,\varphi\left[\frac{a\,b^3}{3} - \frac{64}{b}\sum \frac{e^{\frac{1}{2}ma} - e^{-\frac{1}{2}ma}}{m^5\left(e^{\frac{1}{2}ma} + e^{-\frac{1}{2}ma}\right)}\right];$$

or

$$\mu = G\,\varphi\,b^3\left[\frac{a}{3} - 0{,}2101\,b + 0{,}4183\,b\left(\frac{1}{1^5}\cdot\frac{e^{-\frac{\pi a}{2b}}}{e^{\frac{\pi a}{2b}} + e^{-\frac{\pi a}{2b}}} + \frac{1}{3^5}\cdot\frac{e^{-\frac{3\pi a}{2b}}}{e^{\frac{3\pi a}{2b}} + e^{-\frac{3\pi a}{2b}}} + \cdots\right)\right],$$

a converging formula which may be restricted to the two first terms, when a exceeds $4\,b$. The letter e designates the base of the Napierian logarithms; Σ designates a sum embracing an infinite number of terms, obtained by substituting $\frac{(2n-1)\pi}{b}$ for m and making successively $n = 1, 2, 3 \ldots \infty$. The dangerous points are at the middle of the greater sides a. The sliding is nothing at the sharp edges, although they would be the fibres most exposed if the sections had continued plane. Taking the moment $\mu = G\,\varphi\,a\,b^3\left(\frac{1}{3} - K\,\frac{b}{a}\right)$, and the maximum shearing stress $T = K'\,G\,b\,\varphi$, we should have for K and K', according to different values of the ratio $\frac{a}{b}$ of the sides, the following values;

$\frac{a}{b}$ =	1	1·1	1·2	1·3	1·4	1·5	1·8	2	3	∞
K =	0·193	0·197	0·201	0·203	0·205	0·206	0·208	0·209	0·210	0·210
K′ =	0·675	0·720	0·759	0·793	0·822	0·848	0·904	0·930	0·985	1·000

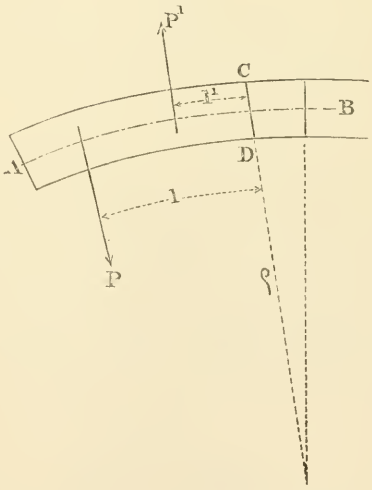
Sections in the form of a *cross* are unfavourable for torsion.

In the preceding formulæ, the coefficient G, of the elasticity of sliding, is supposed constant in all the transverse directions, but it may have another value in the longitudinal direction, as would be the case in prisms of wood. The formulæ may be modified to adapt them to the case where there are two different coefficients G′ and G″ in the directions of the abscissa x and the ordinate y, of the transverse section; but in practice the former case is the most important one.

Flexure.

16. Let A B (Fig. 3), be a prism subjected to transverse forces P, P′, . . . which alter the primitive parallelism of the sections by

Fig. 3.

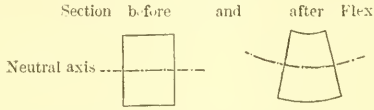


bending all the fibres. Any section C D tends to turn as on a pivot under the action of the bending moment $\mu = Pl - P'l' + \ldots$ exerted by the forces situated between this section and one of the

extremities, A, of the solid. When the forces are all normal to the length of the prism, the mean fibre A B (locus of the centres of gravity of the sections for a homogeneous solid), bends into a curve without change of length. It separates the other fibres into two groups, one of which suffers elongations, the other contractions. These variations $\left(= \frac{v}{\rho} \right)$ are proportional to the distance v of the various fibres from the neutral section, and inversely proportional to the radius of curvature ρ due to the flexure.

Now we know (Art. 5) that an extended fibre contracts transversely, while a shortened fibre swells. It results from this that the section C D will change its form; if, for example, it was rectangular, it will become a sort of curvilinear trapezium (Fig. 4); the

Fig. 4.

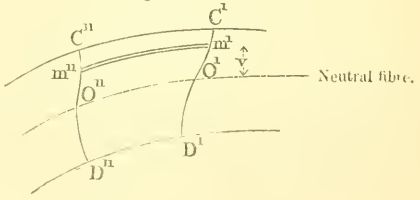


orthogonal lines traced in the primitive section will also be orthogonal in the deformed section.

When the bending moment remains constant for a certain length of the solid, this length bends in the arc of a circle. This case of *circular* or *equal flexure* is the only one in which the transverse sections remain strictly plane after deformation: these sections remain normal to the arched fibres, and neither slidings nor lateral pressures are developed between the fibres.

17. When the prismatic solid is subjected to a bending moment which varies from one section to another, the flexure is said to be unequal. There are then produced slidings between the sections, and even between the fibres. The longitudinal slidings between the fibres develop, among themselves, tangential reactions or frictions of adherence, energetic in the neighbourhood of the central fibre, but which decrease and vanish in the fibres of the external contour which are supposed free. This law of the slidings compels the transverse sections, which were originally plane, to undulate in curved surfaces C′ O′ D′ (Fig. 5), cutting normally

Fig. 5.



the external faces of the solid. Further, the slidings between the different threads of particles produce inverse effects of such a nature that no alteration occurs in the longitudinal stresses of the fibres; thus the fibre $m' m''$, having a section $= d\omega$, will be lengthened by a quantity $= \frac{v}{\rho}$, which implies a tension $\mathrm{E}\, d\omega \frac{v}{\rho}$, the same as if the sections had remained plane in deviating, (ρ designating the radius of curvature of the flexure of the element O O′ of the mean fibre, at first rectilinear). It is this which enables us to study the flexure on the simplifying hypothesis of the sections remaining plane, when we have only in view the tensions or compressions of the fibres. But when we wish to study the slidings (which, however, are less important), exactitude requires that we should consider the true form of the deviated sections, on which depends the variable sliding between the various fibres. The law of the curvatures C′ O′ D′ is such that the resultant of the lateral sliding resistances upon a fibre $m' m''$ is in equilibrium with the resultant $\mathrm{E}\, v\, d\omega \left(\frac{1}{\rho'} - \frac{1}{\rho''} \right)$ of the pressures on the two bases, a resultant due to the variation of the radius of curvature ρ between O′ and O″. As to the effects of swelling and contraction shown in Fig. 4, there is nothing to prevent their development without causing normal lateral pressures between the contiguous fibres.

The tension $\mathrm{E}\, d\omega \frac{v}{\rho}$ of the element of fibre $m' m''$ (Fig. 5) has for its moment $\mathrm{E}\, d\omega \frac{v^2}{\rho}$ relatively to the neutral axis of the transverse section. The integral of this last expression will express the moment of the elastic forces which ought to maintain in equilibrium the given bending moment μ exerted by the external forces applied to the solid. Hence the equation of elasticity $\frac{\mathrm{E\,I}}{\rho} = \mu$, where I designates the moment of inertia, $= \int v^2 d\omega$, of the section of the bent prism in respect to the neutral axis. This equation determines the curvature $\frac{1}{\rho}$ of the mean fibre. For a straight beam the curvature resulting from the simple flexure is generally very small, and is expressed approximately by $\frac{d^2 y}{d x^2}$, in terms of the abscissa x and the ordinate y of any point of the mean fibre. It is necessary then to integrate twice the equation

$\mathrm{E\,I}\dfrac{d^2y}{dx^2} = \mu$ in order to arrive at the finite equation in terms of x and y of the deformed mean fibre.

18. The practical object in the calculation of the strength is, not so much to obtain this deformed figure as to establish the stability of the work. Now if the fibre most strained, C′, is at a distance v' from the neutral axis, we desire that its stress $\mathrm{E}\dfrac{v'}{\rho}$ per superficial unit shall be limited to a given amount R. Substituting, then, $\dfrac{\mathrm{R}}{v'}$ for $\dfrac{\mathrm{E}}{\rho}$, we transform the equation of elasticity $\dfrac{\mathrm{E\,I}}{\rho} = \mu$, into an equation of resistance $\dfrac{\mathrm{R\,I}}{v'} = \mu$, in which $\dfrac{\mathrm{R\,I}}{v'}$ is the *moment of resistance*. According as the ordinate v' is taken on one side or the other of the neutral axis, R will designate the maximum tension or the maximum compression.

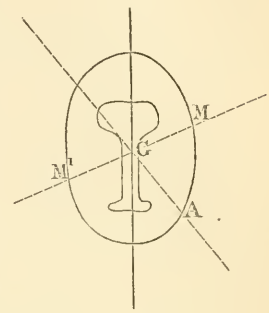
19. When the external forces, being always supposed situated in the plane of the figure, are not normal to the prism, they may exert, besides the moment of flexure μ, a longitudinal force N, spread uniformly over the area ω of the section. There are then two simultaneous effects compounded on the various fibres, and the equation of resistance becomes $\mathrm{R} = \dfrac{\mathrm{N}}{\omega} \pm \dfrac{v'\mu}{\mathrm{I}}$. The mean fibre, the geometrical locus of the centres of gravity or of elasticity, is no longer neutral, for it has to resist the stress $\dfrac{\mathrm{N}}{\omega}$. The neutral point (or point of no pressure), and the centre of stress (the point of application of the resultant of the stresses of the fibres), are situated on opposite sides of the centre of gravity (or of elasticity) of the section, following the same reciprocal law as the axes of suspension and oscillation in the compound pendulum.

20. *Deviated Flexure.* We have, hitherto, only considered plane figures, assuming implicitly the symmetry of the solid and of the forces relatively to the plane of the figure. Let us now suppose, as before, that all the forces act in the same plane, but that this plane of "solicitation" is not in the direction of a principal axis of inertia of the transverse section considered.

Let us revert, in the first place, to the idea of the ellipse of inertia. Take any section, as for example a double T (Fig. 6), calculate its moment of inertia round an axis G M, and then take a length G M or G M′, proportional to $\dfrac{1}{\sqrt{\mathrm{I}}}$. If the axis G M be

made to vary in direction by turning round G, the locus of the points M will be the ellipse of inertia relative to the point G; the ellipse is called central, when G is the centre of gravity of the section. As the ellipse possesses two principal axes, the given section, however irregular it may be, will also have two principal moments of inertia round the same rectangular axes. Now suppose that the plane of solicitation cuts the plane of the section otherwise than in the direction of a principal axis, as in the line G M, for example. Then the neutral axis round which the section pivots by the flexure will not be perpendicular to G M, but will follow the direction of the diameter G A, conjugate to G M in the ellipse of inertia. Consequently the mean fibre will, under the action of the force upon it, deviate outside the plane of solicitation.

Fig. 6.



This general case is but rare in practice. It is easily treated by the equation $\frac{R I}{v'} = \mu'$, taking care to refer I and v' to the neutral axis G A, and to take for μ', not the given bending moment μ, acting in the direction G M, but its projection $\mu \sin (A G M)$ on the plane perpendicular to G A.

We may also decompose the oblique flexure into a flexure of descent and a flexure of deviation, produced respectively by the projections of μ upon the two principal planes of inertia. Then, when we wish to seek the fibre which is most strained, we must accumulate the stresses arising from the two component flexures.

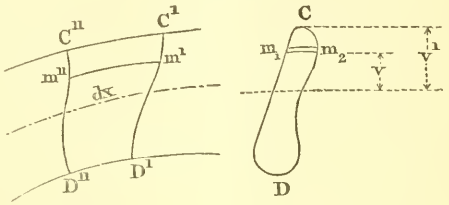
For bent curved bodies, such as the arches of bridges, the equation of resistance, properly so called, will be the same as for a bent prism. But the study of the elastic deformation is more complicated (Art. 26). This deformation has an influence on the reaction of the supports, and consequently, upon the bending moment.

21. *Sliding due to Flexure.*—When the bending moment μ arises from external forces not reducible to a couple, the resultant of the projections of these forces on the plane of the section constitutes a shearing force, causing slidings and undulations of the sections (Art. 17). When we already know the moment μ for the section whose abscissa is x, the shearing force upon the same section may be deduced therefrom, being simply the differential coefficient $\frac{d\mu}{dx}$.

The sliding on the section for any point is the same thing (Art. 5) as the longitudinal sliding between the fibres. But in the case of a piece of wood, it must be remembered that this last sliding is the most to be feared, the fibres being more disposed to slide on each other than to shear transversely.

In the case of small sections, the sliding is determined approximately as follows: Let (Fig. 7) C′ D′ and C″ D″ be the bent pro-

Fig. 7



files of two neighbouring sections, and C D the form of those sections. The equilibrium of the portion C′ m' m'' C″ requires that the difference of the opposing pressures on its bases C′ m', C″ m'', shall be counterbalanced by the resistance of sliding upon m' $m'' = d\,x$. If the breadth $m_1\ m_2$ is $= u$, this last resistance is expressed by $\mathrm{G}\,g\,u\,dx$, or by $\mathrm{T}\,u\,dx$; (G = modulus of elasticity, g = sliding, T = shearing stress per unit of surface). On the other hand, the small slice $m_1\ m_2$, whose surface is $= u\,dv$, supports a normal pressure $\frac{\mu\,v}{\mathrm{I}}\,u\,dv$; consequently C $m_1\ m_2$ will support $\frac{\mu}{\mathrm{I}}\int_v^{v'} u\,v\,dv$. The difference between two pressures, analogous and opposite, in passing from C′ m' to C″ m'' will be the differential relative to μ, that is $\frac{d\,\mu}{\mathrm{I}}\int_v^{v'} u\,v\,dv$, or $\frac{\mathrm{F}\,d\,x}{\mathrm{I}}\int_v^{v'} u\,v\,dv$, where F is the shearing force $= \frac{d\,\mu}{d\,x}$. The equilibrium then gives

$$\mathrm{G}\,g\,u = \mathrm{T}\,u = \frac{\mathrm{F}}{\mathrm{I}}\int_v^{v'} u\,v\,dv.$$

22. If the section C D is rectangular, u is constant, and the maximum sliding which takes place on the neutral axis ($v = 0$) is $\frac{3}{2}$ of the mean sliding $\frac{\mathrm{F}}{\mathrm{G}\,\omega}$ (where ω = area of section).

In a double T of plate iron, the middle web (whose thickness is e, and height $= h$) has in general a section $e\,h$, small in comparison to the top and bottom members; then $G\,g$ or T differs but little from $\frac{F}{e\,h}$, which leads us to calculate the middle web $e\,h$ as if it supported alone the shearing stress spread uniformly over its surface.

In constructions where the breadth u is not small, the transverse sections bend with a double curvature; the sliding may then vary notably upon this breadth. M. de St. Venant has given for this case a theory analogous to that of the torsion, but its practical utility is not great, because in large sections, the effect of sliding is little to be feared.

23. *Continuous beams.* One interesting application of the theory of flexure, is that to continuous beams for bridges of several spans.[1] The reactions exerted on the piers are external forces, which enter into the bending moment and the shearing stress. The difficulty of calculation of these reactions arises from their being dependent on the change of form; it is evident that, according to the way in which the continuous beam undulates under the loads, it may more or less relieve, or even quit altogether, certain supports in order to press more upon others. The absolute lifting off the supports being only an exceptional case, it is admitted as a fundamental hypothesis that all the points of the mean fibre corresponding to the piers and abutments are compelled to remain fixed, and consequently (for a straight horizontal beam) at the same invariable level; then the case of lifting off a support would be revealed by a negative value of the reaction, a value which would indicate the necessity of applying a counterweight, or an anchoring down, or of making a new calculation by suppressing the useless support.

Admitting combinations of load, of such a nature that the various spans carry loads uniformly distributed, but variable from one span to another, the equation of Clapeyron, which connects the bending moment upon three consecutive supports, resolves the problem in a

[1] One of the earliest applications of the modern theory of continuous beams to practical engineering purposes was made by the translator of this Paper in 1850, and will be found recorded in the Minutes of Proceedings of the Institution, vol. ix., p. 257. A certain wrought-iron bridge of this kind had been formally rejected by Captain Simmons, R.E. (the Inspector of Railways under the Board of Trade), as insufficiently strong; but these calculations, corroborated by experiments made on the bridge, demonstrated that the opinion of the Inspector was erroneous, and the prohibition to open the bridge was withdrawn.

The theory was further developed by the translator (at the request of the late Mr. Robert Stephenson), for the purpose of application to the Britannia Bridge, and the calculations were given by him in Mr. Edwin Clark's work on this structure, 1850, pp. 239 to 292; 770 to 787.—Tr.

convenient manner.[1] M. Bresse has extended and enlarged this subject in the third part of his "Mecanique Appliquée," and he has placed the results within the reach of all practical men by means of an atlas, ready prepared of diagrams, of the maximum bending moments at all points. These only require a very simple transformation in the particular application; they only assume certain relations between one of the two extreme spans (which are equal) and one of the intermediate spans (which are also equal among themselves), but as the absolute lengths, as well as the intensities of the permanent and variable load remain arbitrary, it is necessary to amplify the diagram according to the particular data, and at the same time to combine the ordinates of the permanent load and of the moving load or "surcharge." on the same side of the axis of the abscissæ, in order to facilitate the comparative application of the moments of resistance.

The long calculations for bridges of many spans are therefore simplified, or even rendered unnecessary in ordinary cases. But the two following observations dictate a certain reserve in the application.

1. The formula of Clapeyron assumes the moment of inertia of the beam constant throughout its whole length. A more general hypothesis would render the calculation inextricable. Now the object is precisely to arrive at a considerable variation of the dimensions of the transverse section by making it proportional to the magnitude of the stresses. When this alteration is effected the calculations are no longer exact; it would therefore be desirable that the theory should enable us to overcome the difficulty of the general case. According to the analogy of certain simple cases the adoption of the beam of equal resistance would only tend to augment from $\frac{1}{8}$ to $\frac{1}{6}$ the moments upon the supports, and to reduce slightly those at the middle of the spans. On this account the thicknesses in the neighbourhood of the piers should be slightly increased.

2. The hypothesis of points of support maintained at an invariable level is the most legitimate one upon which the formulæ can be established; but it must not be overlooked that the practical realization of this condition is scarcely under control, and if it is not entirely fulfilled, the calculations are incorrect. In every practical case we must expect slight irregularities or subsequent changes which alter the original regularity. Besides, even if the piers were mathematically levelled, we could not be sure that the beam should be so perfectly constructed that this mathematical accuracy should express its natural state previous to the action of the loads. It would seem that in order to acquire an exact know-

[1] This case is treated in the calculations referred to in the previous Note.—Tr.

ledge of the conditions, it would be necessary to ascertain experimentally the reactions exercised by the various piers in order to compare them with those given by calculation.

24. *Lattice girders* may present, according as their bars are more or less close, all possible gradations between a state of rigidity similar to that of a solid side, and the state of a simple assemblage of articulated bars. Under the uncertainty that the question presents, it is customary to calculate lattice girders on the principle of articulated systems. The stiffness of the connections, which is neglected, appears in general to supply an additional guarantee of stability, assuming that the flexures are very small; for otherwise, the curvatures generated might falsify some of the results and cause increased stress on some of the bars.

25. *Rupture imminent by flexure.* When the elongation δ of a fibre becomes excessive, the tension is no longer expressible by $E\,\delta$, it is an unknown function $f(\delta')$. If the most extended fibre, situated at a height v' above the neutral axis, is stretched to an amount δ per unit of length, any fibre whatever of the ordinate v will lengthen a quantity $= \frac{v}{v'}\delta'$. Calling u the variable breadth of the transverse section, and marking the compressed parts with the index 1 (the symbols v_1 being negative v's), the equilibrium of translation of the section first requires

$$\int_0^{v'} u\,dv\, f\left(\frac{v}{v'}\delta'\right) = \int_0^{v'_1} u_1 \,.\, d\,v_1 f_1\left(\frac{v_1}{v'}\delta'\right).$$

Then, in order to maintain the equilibrium of rotation against the bending moment μ, one must have

$$\mu = \int_0^{v'} u\,v\,dv \,.\, f\left(\frac{v}{v'}\delta'\right) + \int_0^{v'_1} u_1 v_1 dv_1 \,.\, f_1\left(\frac{v_1}{v'}\delta'\right).$$

M. Barré de St. Venant has proposed to make

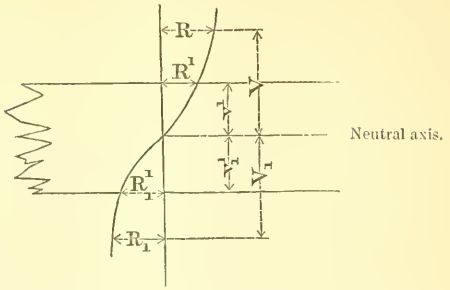
$$f\left(\frac{v}{v'}\delta'\right) = \mathrm{R}\left[1 - \left(1 - \frac{v}{\mathrm{V}}\right)^m\right]$$

for the stretched side, and

$$f_1\left(\frac{v_1}{v'}\delta'\right) = \mathrm{R}_1\left[1 - \left(1 - \frac{v_1}{\mathrm{V}_1}\right)^{m_1}\right]$$

for the compressed side, R and R_1 being (Fig. 8) the stresses of rupture for tension and compression, at the distances V, V_1 from the neutral axis. These distances would be diminished to v_1 and v'_1 (at least one of them) at the instant of actual rupture. The exponents m and m_1 would be numbers > 1.

Fig. 8.



If it is the extended fibre which threatens to fail first, and it becomes necessary to limit the tension to a value R′, we put

$$R' = R\left[1-\left(1-\frac{v'}{V}\right)^{m}\right]$$

$$= \frac{m\,R\,v^{1}}{V}\left(1-\frac{m-1}{2}\cdot\frac{v'}{V}+\frac{m-1}{2}\cdot\frac{m-2}{3}\cdot\frac{v^{1\,2}}{V^{2}}-\cdots\right).$$

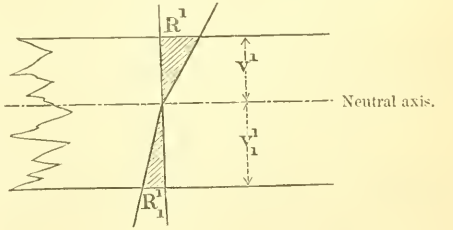
Further, since experience seems to show that a similar law of proportionality regulates the small tensions and the small compressions, it is desirable to unite tangentially at the neutral axis, the curves representing the tensions and the compressions of the fibres. This condition requires that

$$\frac{df}{dv}=\frac{df_1}{dv_1} \text{ for } v=v_1=0,$$

$$\text{or } \frac{m\,R}{V}=\frac{m_1\,R_1}{V_1}.$$

Certain authors omit the condition just mentioned, and make the stresses vary uniformly, but a different rate for tension and for compression. Then the figure representing the pressures (Fig. 9) will present a break upon the neutral axis; the two

Fig. 9.



volumes shaded are equivalent by the condition of equilibrium of translation, which determines the situation of the neutral axis;

and if the section is a rectangle whose breadth is $= a$ and height $= h$, the equation of resistance would be $\mu = \mathrm{R}' \frac{a h v'}{3}$, or $\mu = \mathrm{R}_1' \frac{a h v_1'}{3}$. One or other of these formulæ is employed, according as it is the upper or lower fibre which ought first to fail. In every case the moment of resistance exceeds the value $\mathrm{R}' \frac{a h^2}{6}$, which would be attributed to it by the ordinary theory.

The non-uniformity of the variation, or the adoption of the condition of tangential union at the neutral axis, as above mentioned, will also contribute to increase the moment of resistance. If, for example, it is the extended fibre which ought to give way, and if we admit the neutral axis at half the height by making

$$\mathrm{V} = v', \ \mathrm{R} = \mathrm{R}', \ m = m_1, \ \mathrm{R} = \mathrm{R}_1, \ \mathrm{V} = \mathrm{V}_1,$$

we shall have $\mu = \mathrm{R}' \frac{a h^2}{6} \cdot \frac{3 m (m+3)}{2 (m+1)(m+2)}$.

For cast iron we may be led to admit the law of uniform variation on the side of compression, *i. e.*, to make $m_1 = 1$, leaving m undetermined. Making, further, $\mathrm{V} = v'$, $\mathrm{R} = \mathrm{R}'$, we should be led to

$$\mu = \mathrm{R}' \frac{m a h^2 \left(3 \frac{m+3}{m+2} + 4 \sqrt{\frac{2}{m+1}} \right)}{6 (\sqrt{2} + \sqrt{m+1})^2}.$$

Compound Deformations.

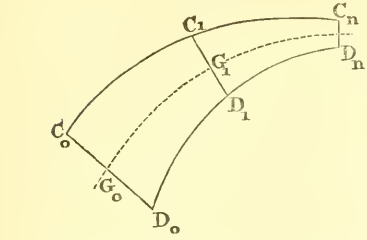
26. Any elastic solid may be subjected simultaneously to stresses of pressure, shearing, flexure, and torsion, which, in combination may either increase or diminish their respective effects, according to the nature of the case.

Formulæ for the general deformation of curved structures. The deformation of curved structures has been especially studied by MM. Bélanger and Bresse. We will give the general results, as extended by M. Bresse.

Let $\mathrm{C}_0 \mathrm{D}_0 \mathrm{D}_n \mathrm{C}_n$ (Fig. 10) be a curved solid whose section varies slowly. In order to study the elastic forces developed on a section $\mathrm{C}_1 \mathrm{D}_1$, we consider the action of the external forces applied between $\mathrm{C}_1 \mathrm{D}_1$ and one, $\mathrm{C}_n \mathrm{D}_n$, of the extremities of the solid. These forces may produce, simultaneously, upon the section $\mathrm{C}_1 \mathrm{D}_1$ a longitudinal stress $= \mathrm{N}$ (perpendicular to $\mathrm{C}_1 \mathrm{D}_1$), a shearing stress $= \mathrm{F}$, a bending moment $= \mu$, and a moment of torsion $= \mu'$. It will then be necessary to make a composition of the various motions excited by the different causes, in order to obtain the final

displacement of the section $C_1 D_1$. The shearing stress F, and the moment of torsion μ' would require, in exactness, that we should take account of the bending of the sections; but, attributing to them a slight influence in the problem, we shall content ourselves here with treating them as uniform shearing (Art. 8) and cylindrical torsion (Art. 11). When we have expressed the elementary displacement of a section, it will be necessary to accumulate or integrate all these displacements between an initial section $C_0 D_0$ and that $C_1 D_1$ where we stop, in order to ascertain the definitive situation of this latter.

Fig. 10.



Let us now refer all to a system of rectangular axes Ox, Oy, Oz. The index 0 will characterize the initial point G_0 of the mean fibre, and the index 1 the point G_1 under consideration. The sign Δ will indicate the increments; thus Δx_1 is the displacement, in abscissa, suffered by the point G_1 in virtue of its deformation. Let θ, θ', θ'', and β be the respective angles which the axis of flexure or of rotation of the section makes with the co-ordinate axes Ox, Oy, Oz, and with the plane of the moment μ. Let F_x, F_y, F_z, be the projections of F on the axes; I the moment of inertia of the section referred to the axis of flexure; I' its polar moment of inertia round the centre of gravity; ω its area; E and G the moduli of longitudinal and transverse elasticity; ds the elementary arc of the curve $G_0 G_1$; and finally m_0, m'_0, and m''_0 the components of the rotation experienced by the initial section $C_0 D_0$. The displacements of the point G_1 are expressed by the formulæ;

$$\Delta x_1 = \Delta x_0 + (z_1 - z_0) m'_0 - (y_1 - y_0) m''_0 + \int_{x_0}^{x_1} \left(\frac{N}{E\omega} + \frac{F_x}{G\omega} \frac{ds}{dx} \right) dx$$

$$+ \int_{s_0}^{s_1} \left\{ z_1 - z \right) \left(\frac{\mu'}{GI'} \frac{dy}{ds} + \frac{\mu \sin \beta \cos \theta'}{EI} \right) - (y_1 - y) \left(\frac{\mu'}{GI'} \frac{dz}{ds} + \frac{\mu \sin \beta \cos \theta''}{EI} \right) \Big\} ds;$$

$$\Delta y_1 = \Delta y_0 + (x_1 - x_0) m''_0 - (z_1 - z_0) m_0 + \int_{y_0}^{y_1} \left(\frac{N}{E\omega} + \frac{F_y}{G\omega} \frac{ds}{dy} \right) dy$$

$$+ \int_{s_0}^{s_1} \left\{ (x_1 - x) \left(\frac{\mu'}{GI'} \frac{dz}{ds} + \frac{\mu \sin \beta \cos \theta''}{EI} \right) \right.$$

$$\left. - (z_1 - z) \left(\frac{\mu'}{GI'} \frac{dx}{ds} + \frac{\mu \sin \beta \cos \theta}{EI} \right) \right\} ds;$$

$$\Delta z_1 = \Delta z_0 + (y_1 - y_0)\, m_0 - (x_1 - x_0)\, m'_0 + \int_{z_0}^{z_1} \left(\frac{N}{E\omega} + \frac{F_z}{G\omega} \frac{ds}{dz} \right) dz$$

$$+ \int_{s_0}^{s_1} \left\{ (y_1 - y) \left(\frac{\mu'}{GI'} \frac{dx}{ds} + \frac{\mu \sin \beta \cos \theta}{EI} \right) \right.$$

$$\left. - (x_1 - x) \left(\frac{\mu'}{GI'} \frac{dy}{ds} + \frac{\mu \sin \beta \cos \theta'}{EI} \right) \right\} ds.$$

If an elevation of temperature produced a linear dilatation τ, we should take account of it by adding respectively, to the first members of these three formulæ, the terms

$$\tau (x_1 - x_0),\ \tau (y_1 - y_0) \text{ and } \tau (z_1 - z_0);$$

but at the same time it would be necessary to introduce into the estimation of N, F, μ, and μ' the forces which would result from external obstacles opposed to the dilatation.

Beside the displacement of the point G, it is necessary also to ascertain the rotation suffered by the corresponding section $C_1 D_1$. The components of this rotation, in the direction of the three coordinate axes, are

$$m_1 = m_0 + \int_{x_0}^{x_1} \left(\frac{\mu'}{GI'} + \frac{\mu \sin \beta \cos \theta}{EI} \frac{ds}{dx} \right) dx;$$

$$m'_1 = m'_0 + \int_{y_0}^{y_1} \left(\frac{\mu'}{GI'} + \frac{\mu \sin \beta \cos \theta'}{EI} \frac{ds}{dy} \right) dy;$$

$$m''_1 = m''_0 + \int_{z_0}^{z_1} \left(\frac{\mu'}{GI'} + \frac{\mu \sin \beta \cos \theta''}{EI} \frac{ds}{dz} \right) dz.$$

27. The most useful application is that to the arches of metal bridges. There is then no torsion μ', and even the shearing stress F may also be neglected as of slight influence. Moreover, the forces are weights all acting in the plane of symmetry of the arch, and the deformation is plane ($\Delta z_1 = 0$). The span ($= 2a$) of the arch is supposed to be maintained invariable by perfectly stable abutments. We therefore annul, in the expression of Δx_1, the quantities Δx_1, Δx_0, y_1, y_0, and x_0; we make $x_1 = 2a$, $\sin \beta = \cos \theta'' = 1$, and we are led to

$$2\tau a + \int_0^{2a} \left(\frac{\mu y}{EI} \frac{ds}{dx} + \frac{N}{Ew} \right) dx = 0.$$

We shall indicate in Art. 13 of another memoir[1] (on the Arches of Bridges) how the thrust of the arch upon the support may be deduced from this equation combined with those of a statical nature.

[1] This will be hereafter printed in the Minutes of Proceedings of the Institution.

28. *Formulæ of M. Barré de St. Venant.* When a point of the section of a solid is subjected, simultaneously, to a longitudinal extension δ_x per unit of length, to a lateral extension δ_y normal to the preceding, and to a transverse sliding g, these effects combine in a resultant stretching, which is variable in the different assignable directions. In one direction r, making (on the plane $x\,y$) an angle a with the longitudinal axis of x, the elongation, which is supposed small, is expressed by

$$\delta_r = \delta_x \cos^2 a + \delta_y \sin^2 a + g \sin a \cos a.$$

The maximum takes place in the direction determined by

$$\text{tang } (2\,a) = \frac{g}{\delta_x - \delta_y}\,;\ \text{and its value is}$$

$$\tfrac{1}{2}\,(\delta_x + \delta_y) + \sqrt{(\delta_x - \delta_y)^2 + g^2}.$$

If δ_y is only the lateral contraction $-\,k\,\delta_x$, caused (Art. 5) by the extension δ_x, the maximum resulting elongation will be

$$\frac{1-k}{2}\,\delta_x + \tfrac{1}{2}\sqrt{(1+k)^2\,\delta^2_x + g^2}.$$

The value of k has little influence; admitting $k = \frac{1}{4}$, the formula will be

$$\tfrac{3}{8}\,\delta_x + \tfrac{1}{2}\sqrt{\tfrac{25}{16}\,\delta^2_x + g^2}.$$

Thus, in order to confine the maximum stretching to a given limit $\frac{\text{R}}{\text{E}}$ or $\frac{\text{T}}{2\,\text{G}}$ (Art. 8), it will be necessary to put

$$\frac{(1-k)\,\text{E}\,\delta_x}{2\,\text{R}} + \sqrt{\frac{(1+k)^2\,\text{E}^2\,\delta^2_x}{4\,\text{R}^2} + \frac{\text{G}^2\,g^2}{\text{T}^2}} = < 1$$

for all the points of the solid; R is the given limit of tensile stress and T that of shearing stress. If the body is fibrous in the longitudinal direction, the formula holds good with a simple alteration of the value of k, provided that the texture is the same in all the transverse directions.

In the case where the body is only subjected to a longitudinal tension N, accompanied by a shearing stress F, the former of these forces, considered as isolated, requires a section $\omega''' = \frac{\text{N}}{\text{R}}$; the other demands a different area ω''; for example, $\omega'' = \frac{\text{F}}{\text{T}}$ if the section continues plane, or $\omega'' = \frac{3}{2}\,\frac{\text{F}}{\text{T}}$ for a thin rectangle bent edgewise (Art. 22), &c. Then the equation of cohesion would lead us to deduce

from this the effective area ω suitable to the two stresses superposed; that would be

$$\omega = \left(\frac{1-k}{2}\right)\omega''' + \sqrt{\frac{(1+k)^2\omega'''^2}{4} + \omega''^2}.$$

If N were a compression, we might make $\omega''' = k\frac{N}{R}$ (Art. 5), k being about $\frac{1}{4}$, and we should have

$$\omega = -(1-k)\frac{\omega''}{2k} + \sqrt{\frac{(1+k)^2\omega'''^2}{4k^2} + \omega''^2}.$$

29. Suppose, in addition to N and F, a bending moment μ acting in the direction of a principal axis of inertia of the section. The greatest extension is $\frac{N}{E\omega} + \frac{\mu v'}{EI}$ (Art. 19), accompanied by a sliding $g = \frac{F}{G\omega}$, admitting the case where the section is preserved plane. If we calculated the section for F alone, we should make it $\omega'' = \frac{F}{T}$; supposing N to be tension, we should make $\omega''' = \frac{N}{R}$; or, if N is compression, $\omega''' = k'\frac{N}{R}$; finally the flexure μ, being isolated, would require a moment of inertia I_0, given by $\mu = R\frac{I_0}{v_0'}$. We write here v_0' and not v', because the dangerous fibre may not be the same in the case of simple μ as in the compound case. Then the effective section ω, and its effective moment of inertia I ought to satisfy, in the compound case, the equation

$$\left(1 - \frac{\omega'''}{\omega} - \frac{I_0 v'}{I v_0'}\right)\left(1 + k\frac{\omega'''}{\omega} + k\frac{I_0 v'}{I v_0'}\right) = \frac{\omega''^2}{\omega^2},$$ N being tension; or,

$$\left(1 + \frac{\omega'''}{k'\omega} - \frac{I_0 v'}{I v_0'}\right)\left(1 - \frac{k\omega'''}{k'\omega} + k\frac{I_0 v'}{I v_0'}\right) = \frac{\omega''^2}{\omega^2},$$ N being compression.

In a beam which bends freely, with distortion of the sections, it suffices to attribute to the section the strongest of the dimensions required successively by the flexure alone and by the sliding alone.

The theory may be extended to the case where the contexture of the body varies symmetrically round three rectangular planes, but we will pass over this case.

Different stresses, combined, may weaken themselves mutually, instead of magnifying themselves; thus a transverse compression may allow an augmentation of longitudinal stretching, as if it filled the empty spaces between the molecules which are determined by this stretching.

30. An application which occurs in ordinary practice, is that in machinery of a round or square shaft, which is at the same time subject to forces both of torsion and bending.

Let it first be a *circular cylinder*, of a texture uniform transversely. This cylinder, whose radius $= r$, is twisted by a moment μ', bent by a moment μ, and further is stretched by a longitudinal stress N. The torsion μ' produces a sliding $= \frac{2\mu'}{G\pi r^3}$ (Art. 11), and the theory leads to the following equation for the fibre the most strained.

$$\left(\pi r^3 - \frac{4\mu}{R} - \frac{N r}{R}\right)\left[\pi r^3 + \frac{k'}{R}(4\mu + N r)\right] = \frac{4\mu'^2}{T^2};$$

R designates the maximum working coefficient of tension, $\frac{R}{k'}$ that of compression, and T that of shearing. Calling r', r'', r''', the radii which would suffice respectively if the shaft was only bent, only twisted, or only stretched, that is to say,

$$r' = \sqrt[3]{\frac{4\mu}{\pi R}},\ r'' = \sqrt[3]{\frac{2\mu'}{\pi T}},\ \text{and}\ r''' = \sqrt{\frac{N}{\pi R}},$$

the equation of resistance, which determines the effective radius r, may be written,

$$(r^3 - r r'''^2 - r'^3)(r^3 + k' r r'''^2 + k' r'^3) = r''^6.$$

If N were a compression we should make $r''' = \sqrt{\frac{k' N}{\pi R}}$, and the equation would be,

$$\left(r^3 + \frac{r r'''^2}{k'} \mp r'^3\right)\left(r^3 - r r'''^2 \pm k' r'^3\right) = r''^6.$$

The upper signs belong to the upper fibre, and the lower ones to the lower fibre; for it is one or other of these fibres which is most threatened. The coefficient k' having little influence, we may take it $= \frac{1}{4}$.

For a *revolving square shaft*, twisted (μ') and bent (μ), the flexure will be generally produced with deviation (Art. 20) which complicates the problem. Barré de St. Venant has given a table of the results for a series of positions of the shaft. If the flexure predominates, the diagonal position is the most dangerous, and the

side c of the square is determined by the equation $\frac{R c^3}{\mu} = 6\sqrt{2}$.

If, on the contrary, the torsion prevails, we must consider the instant when the sides of the section are horizontal and vertical; that is the dangerous case when $\frac{R\mu'}{T\mu}$ is greater than 1·037, and we then take,

$$\frac{R c^3}{\mu} = \frac{9}{4} + \sqrt{\frac{225}{16} + 23077\left(\frac{R\mu'}{T\mu}\right)^2}.$$

Combination of different Materials.

31. A simple articulated system, analogous, for example, to the simple triangular framing of the Crumlin Viaduct (as originally constructed), may admit without inconvenience the combination of heterogeneous materials; for example, cast iron or wood in the compressed bars, and wrought iron for the ties. Each piece, in effect, is free to apply its power, with the modulus of elasticity properly belonging to it, without risk of involving other pieces beyond their limits of strength. But, in the ordinary cases, more complicated, it will often be difficult to make the heterogeneous members work well together in such a manner as to utilize them all in the best possible way, and within the limits suitable for them respectively. The formulæ of deformation must be referred to in order to ascertain whether the play of a piece is limited by its connection with another. If, for example, we split a wooden beam in order to strengthen it with a vertical web of plate-iron enclosed and pressed between the parts, it will be necessary to establish a suitable ratio between the depths of the wood and of the iron, if we desire that each of the two materials may be strained in given degrees.

Dynamical or "living" Resistance (*Resistance vive*).

32. The resistance of solids exposed to shocks or vibrations is scarcely treated, in the present state of science, by any other than empirical rules, which amount to a reduction of the value admissible for the coefficients of safety. The mode of resistance, properly speaking, is always the same, the difficult point is solely the determination of the greatest stresses acting on the material.

Let us consider a cord holding a body in its fall. At the moment when the cord becomes stretched, the moveable body is animated by a known *vis viva;* and at the end of an instant the cord elongates by a quantity z_1, exerting an increasing effort F,

of which the work $\int_0^{z_1} \mathrm{F}\, dz$ has extinguished the *vis viva;* then the motion is stopped, or rather, there are produced thenceforward a number of inverse oscillations, because the elongation z_1 is too great to maintain a simple statical condition. If the variable stretching z of the cord or rod remains but small, the tension F may be expressed by $\frac{\mathrm{E}\,\omega\, z}{l}$, E being the modulus of elasticity, ω the section of the rod, and l its length. Then the resisting work is

$$= \frac{\mathrm{E}\,\omega}{l} \int_0^{z_1} z\, dz = \frac{\mathrm{E}\,\omega\, z_1^2}{2\,l}.$$

In order to verify the strength, it will suffice to equate this expression with the *vis viva* which expresses the shock undergone, added to the work $\mathrm{P}\, z_1$ of the weight P of the body during the stretching, and then to show that the elongation $\frac{z_1}{l}$ per linear unit deduced from the equation does not exceed the limit admissible consistently with safety. If there be no initial shock, the body being set free without velocity at the moment when the cord begins to stretch, the elongation of the latter attains double the statical amount.

When a rail is tested by the shock of a falling weight, there occurs a phenomenon which is complicated under two points of view; in the first place, because the rules of mechanics only give a rough idea of the maximum intensity of the reaction developed by the shock; and secondly, because the test, in order to be conclusive, ought to be extended to near rupture, beyond the limit of elasticity. Hence it must be left to the province of direct experience to decide the legitimate intensity of the shocks that should be prescribed. Certain observations made on bars of cast iron have appeared to show that the shock of rupture depends solely on the area of the section, and little or nothing on its moment of inertia. This is a fact that requires explanation.

Certain mechanical organs which are constructed expressly to receive shocks, such as hammers, for example, cannot pretend to the conditions of resistance applied to objects less strained. The face of a hammer will necessarily undergo a continuous work of permanent deformation or gradual drawing out; that is a question of wear; the remedy consists, less in the dimensions, than in the durability of the metal employed.

33. Slight vibratory movements should be viewed differently from shocks properly so called. They produce actions less intense or less concentrated, but they are present in all machines, in

bridges, &c. They affect, therefore, the majority of permanent structures, to which the theory of strength is applied. But unfortunately the laws of these periodical motions are so complicated, that it will be a long time, without doubt, before any of the results obtained by theoreticians become available in practice.

In principle the difference that exists between a question of dynamical resistance or elasticity and the same question viewed statically, rests in the introduction of the forces of inertia. Then, according to the theorem of D'Alembert, there will be a fictitious equilibrium between the given applied forces, the molecular stresses developed by the stretching of the fibres, at the instant considered, and finally the forces of inertia which depend on the actual acceleration of the motion. Hence we cannot escape the necessity of considering the law of this intermolecular movement. Scientific researches on vibrations have been made by various authors, especially by MM. Phillips (*Annales des Mines*), and Bresse (*Mécanique Appliquée*, chapter on vibrating beams). We will indicate the results of an interesting case, considered by M. Bresse; that of the transverse oscillations of a beam; this case will at least show the complex form of the expression.

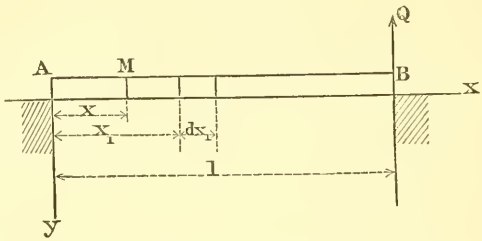
In the first place, let us make a remark which presents a real practical interest, *i. e.*, that a voluntary augmentation of the dead weight may in certain cases lead to a diminution of the maximum stress produced by the sudden application of a moveable load or "surcharge." It will doubtless be understood, without calculation, what is meant by the deadening of vibrations; but, nevertheless, the following simple example, calculated by M. Bresse, may be usefully cited, in order to show how important this effect may be. A rod of 5 mètres long, and 10 square millimètres section, carries a load of 5 kilogrammes; on this weight, another weight, also equal to 5 kilogrammes, is made to fall, from a height of 0·25 mètres; the dynamical work of the rod, in wrought iron, then amounts to $23\frac{1}{2}$ kilogrammes per square millimètre. Now calculation proves that this maximum work will be reduced to 15 kilogrammes, if the immoveable weight suspended at the shackle is increased to 45 kilogrammes, instead of 5.

34. *Transverse vibrations for a homogeneous beam*, of constant section, placed on two supports A and B (Fig. 11), and carrying, per running mètre, a permanent load p, and a moveable surcharge or load p'. The support B exercises a reaction $= Q$; the support A is taken for the origin of the co-ordinate axes Ax, Ay; the length of the beam is $= l$. In the statical condition, the ordinate of flexure of the mean fibre at the point M (whose abscissa is $= x$) would be

$$y = (p + p') \frac{x(x^3 + l^3 - 2lx^2)}{24\,\mathrm{E\,I}},$$

E being the modulus of elasticity and I the moment of inertia of the section, assumed constant. In the case of motion, the

Fig. 11.



inertia would intervene. An element dx_1, of the portion M B would have, in the time t, a force of vertical inertia

$$= -\frac{p+p'}{g}\, dx_1 \frac{d^2 y_1}{dt^2}$$

(where g designates the acceleration due to gravity). Further, the proper mass $\frac{p\, dx_1}{g}$ of the element would have sustained a small rotation $-\frac{dy_1}{dx_1}$, whence the angular acceleration $-\frac{d^3 y_1}{dx_1\, dt^2}$, and, consequently, the couple of inertia

$$-\frac{p r^2\, dx_1}{g} \frac{d^3 y_1}{dx_1\, dt^2}.$$

The letter r designates the radius of gyration of the section. The bending moment is then

$$\mathrm{E\,I}\frac{d^2 y}{dx^2}$$

$$= \int_x^l \left(1 - \frac{1}{g}\frac{d^2 y_1}{dt^2}\right)(x_1 - x)(p+p')\, dx_1 - \int_x^l \frac{p r^2}{g} \frac{d^3 y_1}{dx_1\, dt^2} dx_1 - \mathrm{Q}(l-x).$$

Differentiating twice, we get rid of the signs of integration and of the reaction Q, and we have this equation of the partial differentials of the fourth order.

$$\mathrm{E\,I}\frac{d^4 y}{dx^4} = (p+p')\left(1 - \frac{1}{g}\frac{d^2 y}{dt^2}\right) + \frac{p r^2}{g}\frac{d^4 y}{dx^2\, dt^2}.$$

We arrive at the integration of this equation by means of series. The arbitrary quantities introduced are determined by the conditions of the problem; and especially according to the initial state in which the beam is considered. It is clear, for example, that if this initial state is that capable of maintaining the equilibrium, no

vibrations would be produced; for the forces of inertia only exist, by the hypothesis, through the fact of a primitive anomalous state, which compels the molecules to seek their equilibrium; in pursuing it they pass alternately on one side and on the other, from which circumstance the vibrations arise. Let us then suppose to be given the functions $\varphi(x)$ and $\Psi(x)$, which represent respectively the ordinate of flexure y and its differential coefficient $\frac{dy}{dx}$ in the initial instant, $t = o$. By making

$$\varphi(x) - (p + p')\frac{x(x^3 + l^3 - 2lx^2)}{24\,EI} = f(x),$$

then $\frac{EIg}{p+p'} = h^4$, and $\frac{pr^2}{p+p'} = b^2$, the integral which will express the variable flexure y at every time t, is

$$y = (p+p')\,x\frac{(x^3 + l^3 - 2lx^2)}{24\,EI}$$

$$+\frac{2}{l}\sum_{i=1}^{i=\infty}\left(\sin\frac{i\pi x}{l}\cdot\cos\frac{i^2\pi^2h^2t}{l\sqrt{i^2\pi^2b^2+l^2}}\int_0^l\sin\frac{i\pi x}{l}f(x)\,dx\right)$$

$$+\frac{2}{\pi^2h^2}\sum_{i=1}^{i=\infty}\left(\frac{\sqrt{i^2\pi^2b^2+l^2}}{i^2}\sin\frac{i\pi x}{l}\cdot\sin\frac{i^2\pi^2h^2t}{l\sqrt{i^2\pi^2b^2+l^2}}\int_0^l\sin\frac{i\pi x}{l}\Psi(x)dx\right).$$

The sums Σ comprise an infinite number of terms, the quantity i taking all integral positive values. The duration of the period

$$= \frac{2l}{\pi h^2}\sqrt{i^2\pi^2b^2 + l^2}$$

varying with i, the movement is not periodic, but is produced by the superposition of an infinite number of periodical movements. The strict periodicity would obtain in the case where p would be null; then the duration of the oscillation would be

$$= \frac{2l^2}{\pi}\sqrt{\frac{p'}{EIg}}.$$

If the beam is taken without deformation and without velocity at the origin of the time, that is to say, $\varphi(x) = \Psi(x) = o$, the equation of motion is reduced to

$$\frac{24\,EIy}{p+p'} = x^4 + l^3x - 2lx^3$$

$$-\frac{96\,l^4}{\pi^5}\sum_1^\infty\frac{1}{i^5}\sin\frac{i\pi x}{l}\cdot\cos\frac{i^2\pi^2h^2t}{l\sqrt{i^2\pi^2b^2+l^2}};$$

the sum Σ only extending to the unequal values of i. The motion is nearly periodic, by reason of the quick convergence of the series. The maximum deflexion, thus produced by the sudden application of a load without velocity, reaches double the amount of the statical deflection.

35. When it is wished to consider the influence of the velocity v of transport, by which the extra load may be moved along the beam, it must be remarked that this velocity is equivalent to a centrifugal pressure, nearly vertical, in consequence of the curvature of the trajectory which the moveable body is led to follow on the bent beam. The calculation shows, that under the centrifugal action alone, the maximum bending moment might rise to

$$(p+p')\,\frac{\mathrm{E\,I}\,g}{p'\,v^2}\left(\frac{1}{\cos\dfrac{v\,l}{2}\sqrt{\dfrac{p'}{\mathrm{E\,I}\,g}}}-1\right),$$

instead of the statical value $\dfrac{(p+p')\,l^2}{8}$, on the hypothesis that the moving load is renewed at one extremity in proportion as it leaves the beam at the other. Practically, it might be admitted, that the rolling velocity increases by about one-third the statical effects.

36. In conclusion, it may be remarked, that the theory of the strength and resistance of materials touches obscure problems of the physical constitution of bodies; and yet its practical character obliges it to be simple. Another motive, also, justifies the departure from rigorous exactness, that is, the irregularity of the material facts; if it is good, in effect, to associate mathematical science with physical phenomena, it is incontestable that these two elements, one always logical, the other often capricious, are often divorced from each other. It is on the latitude of the coefficients admitted in practice, that the foundation of security rests, destined to provide both against the risks of the material used and the errors of theoretical hypotheses.

In this limited Paper, the Author has only endeavoured to state the most general theoretical ideas in seeking to bring to view the bases more or less controvertible of the formulæ adopted. It is in reality necessary to weigh well the value of these bases, in order either to appreciate the modifications to be observed in their application, or to discover improvements in them.

In spite of these imperfections, the theory of the strength and resistance of materials in its present state, constitutes an admirable and useful doctrine, which ought to be better known by the majority of constructing Engineers, so much does it tend to impress

boldness and elegance on designs of all kinds. In any case, the theory, imperfect though it be, has the great advantage of generalizing facts. Empiricism, if left to itself, would encumber the science of construction with a mass of rules, without reason or connection, well calculated to repel and mystify practical men themselves. For, as practical men are reluctant to abandon the use of their intelligence, and like to know what they are doing in order to act with confidence, it is necessary that the formulæ should belong to a limited number of types with which they are familiar.

The Author concludes this memoir with the confession that it is very incomplete, for two reasons: first, because there may doubtless exist important works on the subject which he is unaware of, and, secondly, because, even if he had before him the whole of the researches made to the present day, it would not be possible, in a few pages, and in so short a time, to give a perfect résumé of such an important science.

He has accepted, under this reserve, the title proposed by the Institution in their list of Subjects for Premiums, but it would have been presumptuous for him to choose it of his own accord.

The following is a list of works which the Author has quoted and used in the above Paper:—

Bresse. Cours de Mécanique Appliquée. Adopted at the Ecole Impériale des Ponts et Chaussées. 2nd edition. Paris, 1866.

Bélanger. Théorie de la Résistance et de la Flexion Plane des Solides, &c. Paris, 1862.

Barré de St. Venant. Résumé de Leçons sur l'Application de la Mécanique à l'Etablissement des Constructions et des Machines. Paris, 1864.

Phillips; Ingénieur des Mines. Vibrations Intérieures des Solides en Mouvement. Annales des Mines, Vol. X. 1866.

Durand-Claye. Memoirs in the Annales des Ponts et Chaussées. 1867 and 1868.

Contamin. Paper on a New Bridge at Neuilly; Annales du Génie Civil. Feb., 1868.

Gaudard. Etude Comparative de Divers Systèmes de Ponts en Fer. Paris, 1865.

Lavoinne. Sur la Résistance des Portes d'Ecluse. Annales des Ponts et Chaussées.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously, "That there be no meeting on the evening of Tuesday, May 18th, it being Whit Tuesday."

May 25, 1869.

The Session was concluded by a Conversazione, at which the President received the Members of the Institution and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited an interesting collection of mechanical models.

APPENDIX TO VOL. XXVIII.

MEMOIRS.

Mr. JOHN GEORGE BODMER was born at Zurich, in Switzerland, on the 6th of December, 1786. When only a few years old, and scarcely able to handle a knife, he evinced his constructive talents by converting turnips, carrots, and pins into wheels, carts, and other mechanical playthings. As he grew older, these unpromising and perishable materials were soon laid aside and exchanged for wood and iron; in the combination of which, to produce desired effects, he showed great ingenuity.

Young Bodmer, although he was never idle, could not for a long time be brought to see the necessity of going to school; which, considering that the masters in those days took care that instruction and corporal chastisement should have about an equal share of their attention, was not perhaps to be wondered at. However, as soon as his mind, through the earnest representations of his mother, became open to conviction upon this point, he applied himself to the study of those subjects which were then taught at schools (the dead languages excepted) with the greatest diligence and success.

His parents had intended him for a merchant's office, but he evinced such a decided aversion to that pursuit, that they finally determined to let him follow the bent of his mind; and after leaving school, he was accordingly, when about thirteen or fourteen years old, apprenticed to a clever millwright of the name of Mesmer, who carried on business in the Canton of Thurgovia, at some distance from Zurich. Bodmer, finding himself now engaged in occupations congenial to his mind, very soon excelled not only his fellow-apprentices, but also his experienced fellow-workmen, in the execution of the work confided to him, and was, after a short time, relieved from the drudgery which generally falls to the share of the apprentice. His master consulted and employed him in all cases where superior workmanship and knowledge, or especial care and foresight, were required. Mr. Bodmer, in after years, frequently and with great glee told how, on one occasion, he had to help, as confidential assistant, in the construction of a machine which was intended to be endowed with perpetual motion; when, after every unsuccessful trial, his master would observe, that only a trifling alteration was now required to cause

the lever or wheel to pass over the dead point. The apprentice was all the time well aware, and unhesitatingly gave it as his opinion, that the machine would never answer. It is not a little curious that, when yet quite a boy, and before he went to school, Mr. Bodmer, self-taught, practised mechanical drawing; to the great amusement of his companions, who had not the least idea of the meaning of it.

Soon after having served his apprenticeship, Mr. Bodmer erected a small workshop at the village of Küssnacht, on the borders of the lake of Zurich, principally for the execution and repair of mill-wright work. On one occasion, one of the workmen took great care to carry, and display in as conspicuous a manner as possible, a turned iron spindle; the turning of iron being a feat at that time but rarely performed.

As the French Revolution broke out not many years after Mr. Bodmer's birth, and was soon followed by the wars of the French Republic, and subsequently by those of the Empire, it is not surprising that the military character and incidents of the age should have strongly biassed Mr. Bodmer's mind; and it cannot be wondered at that his inventive faculties were directed to improvements in the construction of guns and projectiles, to which he devoted himself in after-life, whenever other occupations left him at liberty to do so. The first task which Mr. Bodmer set himself to accomplish in this direction was to devise a shell which, being fired from a rifled cannon, should explode on striking the object aimed at, instead of requiring a fusee, as usual. This he effected by screwing into the aperture or neck of the shell, where, under ordinary circumstances, the fusee is inserted, a perforated bush of brass, on the top of which, after charging the shell, a capsule of a fulminating compound was placed. Finally, the upper end of this bush was covered by a cap in such a manner that, on the shell striking the object aimed at, the cap was crushed, and coming into violent contact with the explosive compound, the latter was ignited and set fire to the charge. The first shell constructed upon this principle, by way of experiment, was finished on the 1st of January, 1806, and was caused to explode by being dropped from a rock in the immediate neighbourhood of Küssnacht.

Shortly afterwards Mr. Bodmer was introduced to and went into partnership with Baron d'Eichthal, who had purchased the conventual buildings of St. Blaise, in the Black Forest, with the intention of appropriating them to the purposes of a cotton-mill. Workshops were accordingly established, the requisite alterations in the building made, and the water-wheels, shafting, and gearing, as well as the whole of the machinery, constructed and erected according to Mr. Bodmer's own plans, and under his immediate superintendence and direction. The mental and bodily labour at this

juncture was so much the more arduous, as the spot selected was situated in a narrow valley, surrounded by hills of considerable height, and all the materials required for the undertaking, the timber excepted, had to be conveyed from places at a distance over hilly roads; so that Mr. Bodmer's personal attendance, directions, and instructions, in many places were indispensable.

It was about this time that Mr. Bodmer first conceived the idea of what became subsequently known in Germany by the comprehensive name of "Bandvereinigungs System" (Band-uniting system). This consists in placing any suitable, or desirable, number of carding-engines in a row side by side, with their doffers to the front, and causing the same to discharge their slivers simultaneously, through delivery-rollers moving at the same superficial velocity, upon a belt which, travelling along the front of the carding-engines in question, with a linear velocity corresponding with that of the discharge of the slivers, conveyed the latter, laid side by side, in a broad band towards a machine called a lap-machine; where the slivers were wound in successive spiral layers upon a wooden roller, to which, by means of a drum, the same circumferential speed as that of the belt was imparted. As soon as a sufficient quantity of slivers had been wound upon this roller, or lap, it could be, with the greatest facility and despatch, replaced by another wooden roller without stoppage, and the work went on as before. A suitable number of these laps were placed behind the finishing carding-engines, or drawing-frames, as the case might be, upon two or three or any convenient number of unwinding drums, the circumferential velocity of which corresponded with that of the feed or drawing rollers; so that 'doubling' could be carried out to any extent, whilst it was impossible for the slivers to become stretched, or otherwise injured, as they often happened to be on being forcibly withdrawn from the mass compressed into the cans, which then were (and perhaps even now are, at least in England) in general use. The same principle was to be carried out with regard to the slubbing and roving frames, and even to the feeding portion of the spinning machinery. When Mr. Bodmer proposed to his partner that the machinery for their mill should be constructed upon this plan, Baron d'Eichthal expressed himself as being reluctant to permit these innovations, because, as he said, if such a system were at all practicable, or superior to that in common use, it must have been long ago adopted in England. This was so far from being the case that, although Mr. Bodmer's improvements found great favour both in France and in Germany, there was scarcely a trace of them in the cotton-mills of England, forty years after the above recorded objections had been made by Baron d'Eichthal.

The progress of the Napoleonic wars having suggested the

expediency of establishing a manufactory of fire-arms at St. Blaise, a few skilled workmen were sent for from St. Etienne, in France, to form the nucleus of this new branch of manufacture. Instead, however, of confining himself to the ordinary process of gun-making by manual labour, Mr. Bodmer invented and successfully applied a series of special machines by which the various parts—more especially those of the lock—were shaped and prepared for immediate use, so as to insure perfect uniformity and to economise labour. Amongst these machines there was also a planing-machine on a small scale; and Mr. Bodmer has been heard to observe how strange it was that it should not have occurred to him to produce a larger machine of the same kind, with a view to its use for general purposes. A beautifully-finished rifle, having Mr. Bodmer's name and the place of manufacture engraved upon the lock-plate, is now extant; also an equally well-executed breech-loading rifle, with bayonet, intended for the use of infantry, and made according to Mr. Bodmer's plan, about the same time, say between the years 1809 and 1813. As the percussion-lock was not known, Mr. Bodmer had, of course, to contend with great difficulties; and it is scarcely necessary to observe that the principle was never adopted, the time for a change of such magnitude having evidently not yet arrived.

As the operatives for the cotton-mill had to be obtained from the surrounding villages, some of which were situated at a distance of many miles from St. Blaise, and as there were but few houses in the immediate neighbourhood of the former convent, whilst the accommodation in the conventual buildings was most ample, the whole of the workpeople were both fed and lodged in the latter. And in order to save labour in preparing the tables for the meals and in serving up the food, and to render the work of feeding such a large number of people more expeditious and systematic, Mr. Bodmer had a railway constructed, with branches or sidings to every table, upon which the plates, dishes, &c., &c., were conveyed on small trucks, from the kitchen and back again.

The Grand Duke of Baden, appreciating his inventive genius, and his mechanical and administrative talents, and being anxious to secure his services for the benefit of the country, appointed him Director General of the Iron Works, which were Government property. As Mr. Bodmer still retained the management of the establishment at St. Blaise, his time was so much occupied that he generally spent a part of the night in travelling backward and forward, so as to be able to devote the day to his usual duties. He was frequently so intent upon his studies, or upon the accomplishment of any task which he happened to have set to himself, that he would forget to take either food or rest for thirty-six hours together. The climate of the Black Forest is most severe in

winter, the country being covered to the depth of many feet with snow; and Mr. Bodmer had frequently to perform his journeys over the mountains seated in, or astride on, a small open sledge, which, owing to the unevenness of the path, was very apt to become upset.

A further appointment, which was almost forced upon Mr. Bodmer by the Grand Duke, was that of Inspector of the Matériel of Artillery, with the rank of Captain, at a salary of 4,000 florins, or about £400 sterling, a year. In this capacity he had to contend against the apathy, if not hostility, of the General of Artillery, who could not understand either the necessity or the expediency of altering or improving anything to the sight or use of which he had been all his life accustomed. A number of coloured drawings, chiefly made by young artillerists under Captain Bodmer's tuition and direction, are still extant, showing a variety of modifications of and improvements in ammunition-waggons, gun and mortar carriages, &c., designed by him, and carried out to his orders. On one occasion a hammerman pronounced a certain forging intended to form a part of an ammunition-waggon to be impossible of execution, whereupon Mr. Bodmer had to convince him of the contrary, by finishing the work with his own hands.

The time had now arrived for Mr. Bodmer to carry out his improved rifled breech-loading cannon and self-exploding projectile. A cannon, representing on a reduced scale a 12-pounder, and capable of throwing balls of 1 lb. weight, was accordingly constructed, together with the requisite ammunition; and in the year 1812 Mr. Bodmer took this model cannon with him to Paris, with the intention of exhibiting it before the Emperor Napoleon, and if possible inducing him to introduce the invention in the French army and navy. Napoleon happened to be absent from his capital at the time, but Mr. Bodmer being provided with letters of introduction to one of the principal bankers of Paris, as well as to other gentlemen of high standing, an interview between himself and General Laribosière and other French artillery officers was arranged, during which Mr. Bodmer explained the principle and anticipated effects of his new cannon and projectile. For the purpose of affording Mr. Bodmer the opportunity of practically proving the correctness of his statements, one of his friends placed a large garden, situated at some distance from Paris, at his disposal. General Laribosière, with other officers, and several scientific gentlemen, were invited; and in their presence a small wooden structure filled with straw was ignited by the shell, which had purposely not been filled with powder to the bursting point. The military spectators were not prepared to deny the efficiency of the cannon and its projectile, but they contended that the model was too small to admit of reliable conclusions being drawn, as to

what might be expected from a real 12-pounder. Nevertheless it was intimated to Mr. Bodmer that, if he would join the French artillery, his improvements would doubtless be carried out and adopted. This flattering offer was, however, for many reasons declined; and Mr. Bodmer was soon afterwards obliged to return to his post, without having had the opportunity of seeing the Emperor Napoleon. The circumstances attending the experiments with the model cannon were subsequently recorded in the "Bulletin de la Société pour l'Encouragement des Arts et Métiers."

On returning home, Mr. Bodmer determined to construct a real 12-pounder breech-loading cannon. The work was immediately taken in hand; and when all was ready, about the year 1814, the cannon, with its projectiles, was subjected to a series of experiments, during the space of twelve days, on a large common near the town of Carlsruhe. Unfortunately, the General of Artillery under whose direction the proceedings were carried on, insisted upon first of all, and for many days together, firing solid shot; and when at last the time of the shells came, some accident occurred to the apparatus for closing the breech, so that the experiments had to be abruptly brought to a close. It was, however, found that those shells which were tested exploded much as it was expected they would. But it was likewise observed, that when strong charges of powder were used, whether for the solid or the hollow shot, the circle or zone of lead which embraced the projectile (the lead being poured into a dovetailed recess in the body of the ball, so as to cause it to take into and be guided by the rifle grooves) expanded, in consequence of the increased velocity of rotation, and caused the projectile to deviate from its course, finally becoming completely detached. A document recording, after the requisite explanatory remarks, in a tabular form, the particulars which are considered of importance on such occasions, and signed by the officers present at the time, is still in the hands of Mr. Bodmer's relations. This same cannon, after having been repaired, was a few years later sent to England, and on his first visit to that country, in 1816, Mr. Bodmer made various, but ineffectual, attempts to obtain permission from the Board of Ordnance to have the efficiency of the invention tested. There being thus no prospect of success, the cannon was deposited in a warehouse in London, which together with its contents was at a subsequent period destroyed by fire.

In connection with this matter it may be mentioned, as an interesting fact, that at Mr. Bodmer's request, his brother, Mr. J. J. Bodmer, with the model cannon in his possession, undertook a journey to St. Petersburg, with instructions to offer the invention to the Emperor Alexander. Mr. J. J. Bodmer was very favourably received, and requested to inform his brother that on coming

to St. Petersburg the improved system of artillery should be immediately adopted, and all the means necessary for practically carrying out the invention placed at his disposal. The letters conveying these tidings were however either lost or intercepted, and Mr. J. J. Bodmer, receiving no answer, proceeded to England, by way of Sweden, where, some time afterwards, the two brothers met.

Besides attending to the duties which devolved upon him, in consequence of his Government appointments and his connection with the works of St. Blaise, Mr. Bodmer designed, for one of his brothers who was in business at Zurich, a flour-mill, which differed in some essential particulars from the mills then generally in use. Instead of each set of stones being driven by a small waterwheel, the whole of the machinery connected with the mill was set in motion by a waterwheel of unusual size, which as it derived its power from a river (Limmatt), whose water-level was very fluctuating, was fitted with an apparatus for adjusting the dip of the floats; this consisted of two radial arms, in which the bearings of the shaft were placed, and which could be raised and lowered at pleasure by a simple mechanism. The various sets of millstones were symmetrically arranged in groops of four, and driven from a central spurwheel. Each set could be started and stopped separately, and was besides furnished with a contrivance for accurately adjusting the distance between the top and bottom stones. By means of a hoist of simple construction, consisting in fact only of a large and broad-flanged strap-pulley and a rope-drum, both mounted on the same spindle (the latter being hinged at one end, so that it could be raised and lowered by means of a rope), the sacks of grain or flour could be made to ascend and to descend at pleasure, and the operatives themselves could pass from one floor to any other, by simply tightening and releasing the rope. The shafting of this mill was made of wrought iron, and the wheels, pulleys, hangers, pedestals, frames, &c., of cast iron, much in accordance with modern practice. The castings were from the Grand-Ducal Ironworks.

In 1816, Mr. Bodmer for the first time visited England and Scotland, as previously stated. He had letters of introduction which enabled him to gain access to the principal workshops, cotton-mills, woollen-mills and ironworks. He visited Manchester, Liverpool, Derby, Leeds, Sheffield, Birmingham, Glasgow, Edinburgh, and other places of note, and made himself acquainted, as far as the short time allowed would admit, with the principal features of the various branches of industry in which he took the greatest interest.

Mr. Bodmer left the service of the Grand Duke of Baden about the year 1821, his partnership with Baron d'Eichthal having been previously dissolved. He then returned to Switzerland, and was, amongst other things, engaged by a former pupil of his to design

and partly superintend the erection of a cotton-mill at Aarau, in which his improved machinery was to be introduced. Somewhat later he was also commissioned by the proprietors of the Baths of Schinznach, in the Canton of Argovie, who had it in contemplation to completely reconstruct their establishment, to prepare the plans for the new buildings, as well as for the waterwheel, pumps, and other machinery intended to distribute the water and to supply the various bath-rooms. This was accomplished in such a manner that not only the desired temperature was uniformly maintained, but the sulphurous vapours were kept down to such a level as not to annoy the bathers. This machinery was, it is believed, subsequently carried out by Messrs. Fairbairn and Lillie, of Manchester, to whom Mr. Bodmer showed and explained the drawings on his return to England in 1824.

Almost immediately after his arrival in that country, Mr. Bodmer, having in the meantime further matured and improved the new system of cotton machinery previously adverted to, proceeded to take out a patent (No. 5,016—1824), for the invention. Manchester, as the centre of all operations connected with the manufacture of cotton, was selected as his first place of residence. He soon found out, however, and was indeed assured of it by friends, that considering the total novelty of the system of cotton machinery, and the prejudices entertained against foreigners, as well as against their inventions, especially in a branch of industry so peculiarly English in origin and growth, it would be absolutely necessary, in order to establish the efficiency and superiority of the invention to the satisfaction of those who were expected to make use of it, to exhibit the machines at work in a cotton-mill. Mr. Bodmer, therefore, in partnership with a gentleman of the name of Novelli, to whom he had been introduced, and who appeared to understand and to appreciate the merits of the improvements, determined upon adopting this course. A suitable site was found at Egerton, near Bolton-le-Moors; and in order to be as near as possible to the spot selected for the enterprise, as also to the works where the mill-gearing, machinery, &c., was to be executed, Mr. Bodmer took up his residence in Bolton, with a suitable staff of draughtsmen and assistants. Besides this, however, a temporary building, composed of bricks and planks, was erected at a short distance from the mill, where both Mr. Bodmer and his assistants resided for a considerable time, with a view to facilitate the superintendence and direction of the various operations which were going forward. As both the fall and quantity of water were considerable—equal, in fact, to something like 40 H.P., Mr. Bodmer, in order to utilize the fall to the greatest extent, designed a waterwheel of more than 60 feet in diameter, with a shaft of cast iron, with which the cast-iron shrouding was connected radially, and stayed diagonally, by wrought-iron

rods emanating from cast-iron centres on the shaft. The sheet, or plate-iron buckets were each bent to a curve calculated to receive and discharge the water with the least possible disturbance and loss. A further and altogether novel feature of this waterwheel, the plans of which are still in existence, consisted in a peculiar arrangement for providing for the free escape of the air, though not of the water, from the buckets, so as to prevent the disturbance and scattering of the water on its rushing into the buckets as each came round in succession to be filled. An internal wheel, composed of cast-iron segments gearing into a pinion, drove the first motion shaft at a considerable velocity. This waterwheel was partly finished by the well-known Engineers, Messrs. Rothwell, Flick, and Rothwell, of Bolton, when, Mr. Bodmer's health completely failing him, he was obliged to leave England, on which occasion the completion of the whole was intrusted to Messrs. Fairbairn and Lillie. For the purpose of facilitating the operations connected with the erection of the building, waterwheel, &c., Mr. Bodmer, without being aware of the previous existence of such an apparatus—if indeed the invention was not then a new one—constructed what is now called a 'Travelling Crane.' On his return to the Continent, in 1828, and after having recruited his health by a stay of some weeks' duration at the Baths of Pfeffers, in Switzerland, Mr. Bodmer, at the request of Messrs. Hartmann, of Munster, in Alsace, the well-known proprietors of extensive cotton-mills and dye-works, undertook to prepare plans of the new system of cotton machinery, which had also been patented in France, with a view to its introduction into their cotton-mills; and with one or two assistant draughtsmen, went to reside at Munster for a considerable time, for the purpose of directing and superintending the operations. He subsequently spent some time at Zurich, where he continued to further improve his cotton machinery, and also designed a flour-mill, and a blast. or smelting furnace of novel construction.

At the invitation of the Municipality of Geneva, Mr. Bodmer gave in a plan for a bridge over the Rhône, intended to connect two opposite quarters of the town, and in acknowledgment of his services, was presented with a handsome silver salver, bearing a suitable inscription. In 1830, Mr. Bodmer spent some time at Geneva, where he had several friends, amongst them Mr. Fazy-Pasteur, Mr. Martin, and Mr. Duval. The latter had recently come into possession of a small ironworks at Ardon, in the Canton de Valais, and as he wished to have Mr. Bodmer's advice and assistance respecting the most urgent alterations and improvements for putting the place into tolerable working condition, Mr. Bodmer willingly consented to spend a few weeks at these works; whence he returned to Zurich.

During his stay in Alsace, Mr. Bodmer had made the acquaint-

ance of Messrs. de Dietrich, the proprietors of several ironworks in the Department of the Lower Rhine, the principal one of which was situated at Niederbronn, a small town about 30 miles from Strasbourg. Owing chiefly to the somewhat antiquated character of the machinery employed, these ironworks were not, at the time in question, yielding as profitable a return as, in consideration of their favourable situation with regard to fuel and ores, they might have done. Mr. Bodmer was therefore called in and requested to suggest such alterations and improvements as he might consider necessary, or desirable. It was subsequently found that Mr. Bodmer's presence at or near the works would be both more convenient and satisfactory; and he was accordingly invited, about the year 1831, to take up his residence at the then abandoned ironworks of Reichshoffen, situated at a distance of only a few miles from Niederbronn, and about the same distance from another ironworks belonging to the Messrs. de Dietrich. For greater convenience in carrying out the work of improvement then contemplated, a portion of the existing buildings was converted into a smiths' shop, fitting and turning shop, patternmakers' shop, and drawing office; whilst two large sheds served as erecting shops for heavy machinery, and the workmen's cottages were restored to their original use. A new waterwheel for driving the fans, lathes, &c., was also erected, the power to work it being supplied by a stream of water running through the premises. New blast-engines were in the first place designed and constructed for two of the ironworks; and as these were to be actuated by waterwheels, and no machinery for boring out iron cylinders being at hand, the vessels for receiving and discharging the air were simply square wooden boxes, open at the bottom, and with the sides and top strongly jointed together and bound and tied by iron bars. There was, of course, a square piston, also made of wood, except as to its attachments to the piston rod, fitted with a number of springs acting upon adjustable and overlapping pieces of wood which represented the piston rings. The piston was actuated by a lever, one arm of which was connected with the piston rod, whilst at the extremity of the other arm there was a toothed segment, acted upon by a wheel armed with teeth over a portion of its circumference only, and which therefore alternately depressed and released the segment, thus causing the piston, which was counterweighted, to rise and to descend. During the descent of the piston a valve opened, admitting the air into the box, which air was compressed and expelled by the upstroke. There being two such boxes, or air vessels, the piston of the one was caused to descend whilst the other ascended; so that the action of the machine was sufficiently uniform. One of these blast engines was kept continuously at work for more than fifteen years, and answered its purpose remarkably well. These and other minor

improvements and alterations having been carried out, Mr. Bodmer designed and subsequently constructed at Reichshoffen, a mill for rolling bars and a machine for cutting nail rods, which, besides being fitted up in a superior style, embodied many novel features. But it so happened that after this mill had been erected, the manager or director of the ironworks was unable to recognize either the novelty or the superiority of it, and persuaded Messrs. de Dietrich to authorize him to substitute a mill of his own scheming. As the arrangements of the workshops of Reichshoffen, although moderate in extent, were sufficiently large to admit of the execution of other machinery besides that required for the surrounding ironworks, Mr. Bodmer undertook the construction of a waterwheel, shafting, gearing, hangers, pedestals, &c., for a cotton-mill and weaving-shed then recently erected at the village of Uster, near Zurich; and the contract was carried out to the satisfaction of both parties.

As the French government frequently gave Messrs. de Dietrich large orders for cannon balls and shells, in the dimensions of which but a trifling deviation from the true diameter was allowed, Mr. Bodmer not only had most accurate and convenient iron patterns made; but, moreover, introduced an apparatus for the use of the moulders, by means of which these patterns could be drawn out of the sand with the greatest ease and accuracy.

There being now no further necessity for Mr. Bodmer's presence at Reichshoffen, he determined upon returning to England, and arrived there in the summer of 1833. After a short stay in London, he proceeded to Manchester, and then appointed Messrs. Sharp, Roberts, and Co., under agreement, to be the makers of his improved cotton machinery, which they also undertook to recommend and to introduce to the best of their ability. Their exertions were, however, only successful in one or two cases, and the agreement was, not long afterwards, cancelled by mutual consent. In the following year Mr. Bodmer returned to Bolton, where—at the works of Messrs. Rothwell and Co., the Union Foundry—the patterns and machinery left behind on his departure from England, in 1828, had been kept, and where he hired a floor, which was speedily fitted up as a workshop. In May, 1834, Mr. Bodmer obtained two patents (Nos. 6,616 and 6,617), under the respective titles of "Certain Improvements in Steam Engines and Boilers applicable both to Fixed and Locomotive Engines," and "Certain Improvements in the Construction of Grates, Stoves, and Furnaces, applicable to Steam Engines, and many useful purposes." The main features of novelty in regard to the steam-engine consisted in its being fitted with two pistons moving simultaneously in opposite directions, and connected with a double crank: the steam being alternately admitted between the pistons and near the cylinder ends. The advantage of this peculiar arrangement was, that the

thrust and strain occasioned by the pressure of the steam was exclusively sustained by the cylinder and by the cranks, and could not affect either the foundation and frame, or the bearings of the crankshaft of the engine; admitting, therefore, of a high speed, without entailing that wear and tear which takes place in steam-engines of the ordinary construction, and reducing the corresponding piston speed to one-half. Mr. Bodmer immediately proceeded to construct a non-condensing engine upon this double piston or compensating principle, which was also further provided with a mechanism for reducing the pressure upon, and, therefore, the friction of, the slide valve. This consisted simply in a piston placed in a cylinder at the back of the valve box, and connected with the slide valve by a link; so that the steam exerted its pressure simultaneously against the slide valve in one direction, and against the piston in the opposite direction. This first specimen of the double piston engine, after being finished, was simply bolted to posts in the middle of the workshop; and although the cylinder was at least 10 inches in diameter, and allowed to revolve at a speed of more than one hundred revolutions per minute, there was no perceptible shaking or vibration in any part of the building, which was a very old one. It was Mr. Bodmer's idea, that although taking mere size into consideration, the compensating or double piston engine was slightly, perhaps considerably, more expensive than the ordinary one, owing to its requiring a double set of pistons, piston-rods and connecting-rods, as well as a double crank; still, in consequence of the great speed admissible, the engine could be made much smaller and lighter, and the foundations much cheaper, so as to compensate for the additional outlay. But the parties to whom Mr. Bodmer intended to confide the manufacture of these engines declined to become the makers of them or to recommend them, on the plea that through their introduction, the profits of the iron foundry would be curtailed. It is probable that there were other reasons for this refusal; but however that might have been, as the cotton-spinners and others could not see their way any more clearly than the engineers, they talked of complexity of construction, of the dangers of high speeds, and declined to run the risk of patronising so daring an innovation, especially as it emanated from a foreign engineer, who could not be supposed to be an authority in the article of steam engines.

The construction of the fire-grates was based upon the principle, that in order to attain the greatest possible degree of economy in the combustion of pit coal, it was desirable to supply the furnace with fuel at a slow rate, but uniformly and continuously. These considerations led Mr. Bodmer to the adoption of a travelling grate surface, in combination with a hopper and a sliding door, for regulating the depth of the layer of fuel. This object was purposed to

be accompanied either by connecting the grate bars after the manner of links of a pitched chain, passing in front and at the back over a chain drum, one of which drums might either be driven by hand or by power; or by placing removable bars so as to form the circumference of a revolving drum; or else by moving the bars either singly or in sets towards the bridge, dropping them at the bridge end, and causing them to return to their original position by suitable mechanism. It was Mr. Bodmer's intention to have conducted a series of experiments with the moveable-bar grate, and the greater part of the mechanism, as well as a suitable furnace, had already been constructed; but owing to a variety of circumstances these experiments were postponed, or in fact altogether abandoned.

Mr. Bodmer had, in the mean time, still further modified and improved his cotton machinery, chiefly in regard to the mode of winding up the product of the carding-engines, drawing-frame, and slubbing-frame, in which flanged bobbins of any convenient size were substituted for those described in his patent of 1824: the slivers or rovings being laid on to the bobbin by means of tubes or guides fixed upon a slide, to which a reciprocating motion was given. As the periodical stripping of all the top-cards or flats of a carding-engine, by hand, in the usual manner, causes an unequal thickness of the fleece, Mr. Bodmer, after having already, in his patent of 1824, shown a self-acting apparatus for stripping the top-cards one by one, in regular succession, whereby the operation was always performed upon the flat nearest to the licker-in, which was subsequently carried to a position nearest to the doffer, whilst the remaining top-cards were being simultaneously moved backwards towards the licker-in—still further improved and simplified this important mechanism. Another improvement relating to the carding-engine, which, after having been re-invented, was, as an infringement upon Mr. Bodmer's prior rights, adopted to some extent by the cotton-mill owners, consisted in a sharp-edged plate, closely interposed between the feed-roller and licker-in, in such a manner that the feed-roller held the cotton, whilst the licker-in acted upon it. The fibres were thus bent and drawn down over the edge of the plate, and thereby more thoroughly separated and cleansed, at the same time that the feeding was more regular, and the cotton prevented from forming into lumps. These, and other improvements and modifications, were subsequently embodied in a patent, under the title of "Certain Improvements in Machinery for Preparing, Roving, and Spinning Cotton and Wool" (No. 6,841, 1835)—various experimental machines having been previously constructed and tried.

It was about this time that the formation of a railway between London and Birmingham being in contemplation, Mr. Prevost,

of London, one of the directors, invited Mr. Bodmer to give his views as to the best system of rails and carriages. On this occasion Mr. Bodmer proposed the construction of carriages since adopted in the United States of America, in parts of Germany, and in Switzerland, and the distinctive feature of which is, that there is a longitudinal passage through the middle of each carriage, so that the guard can pass from one end of the train to the other with the greatest ease and security.

It had long been Mr. Bodmer's idea, that the mechanism for actuating self-acting mules ought to be placed altogether apart from the mule, and to be capable of simultaneously operating upon two, or any desirable or convenient number of, spinning machines. With this view he planned a self-contained machine, intended to be connected with the mule only by such articulations as the command over the motions of the carriage, rollers, and fallers required. This machine was actually constructed and experimented upon with such success as could reasonably be expected to attend so novel a combination of mechanism. Mr. Bodmer's new system of cotton machinery was to some extent carried out at the mills of Messrs. Bolling, of Bolton. There were also one or two cases of infringement upon small portions of Mr. Bodmer's patents, one of which, at least, was settled by arbitration; the late Mr. Benjamin Hick, a highly valued friend of Mr. Bodmer's, being the arbitrator.

In 1837, Mr. Bodmer took out a patent under the title of "Certain Improvements in Machinery for Spinning and Doubling Cotton, Wool, Silk, Flax, and other Fibrous Materials" (No. 7,388). The principal feature of novelty consisted in a peculiar flyer or guide, whereby, in combination with suitable machinery, the yarn was to be wound upon the bare spindle, in the form of 'pincops,' as in an ordinary mule for spinning. An experimental machine with two spindles was first constructed upon this plan, and it was found that the principle of winding upon the bare spindle by such means was quite correct; but great difficulties were experienced in selecting the proper material from which the flyer was to be made, and a great deal also depended upon the size and shape of this flyer. It was found that sheet iron, or sheet steel was too heavy; wire was apt to get out of shape and to become entangled in the guide-box, and paper and parchment were affected by heat and moisture. A machine containing about the same number of spindles as ordinary 'throstles' was a considerable time afterwards constructed and experimented upon; but sufficiently satisfactory results could not be obtained with the materials for the construction of the flyers at command, and the machine was, therefore, laid aside. There was, however, no difficulty in spinning flax.

Towards the latter part of the year 1837, Mr. Bodmer made the acquaintance of the late Mr. Hugh Hornby Birley, of Man-

chester, who, thinking highly of Mr. Bodmer and his inventions, and being willing to furnish the means of having these inventions carried out, proposed that Mr. Bodmer should transfer his tools, patterns, and machines to Manchester, where, at the Chorlton Mills, belonging to Messrs. Birley and Co., a large room on the ground floor was placed at his disposal; to which was, some time afterwards, added another room of about the same size. At a somewhat later period, a foundry situated at a short distance from the mills, was purchased by Mr. Birley, to which, by altering and repairing existing buildings, and erecting new ones, a pattern-makers' shop, carpenters' shop, fitting-up shop, blacksmiths' shop, and grinding-shop were added, besides a counting-house, drawing-office and storerooms. The power for driving the blowing-fans and other machinery was supplied by one of Mr. Bodmer's patent compensating condensing steam engines. The boiler furnace was also fitted with one of the patent revolving drum-grates, which, however, was not found to answer the purpose as well as had been expected; and as it would have been inconvenient to try further experiments with it, it was subsequently removed, and an ordinary grate substituted for it.

In 1838, Mr. Bodmer took out a patent under the title of "Certain Improvements in Machinery or Apparatus for Carding, Drawing, Roving, and Spinning Cotton, Flax, Wool, Silk, and other Fibrous Substances" (No. 7,837), a schedule of which machinery and apparatus is annexed to this Memoir. It may, however, not be uninteresting to advert more particularly to a modification of the detached self-acting spinning-machine, of which mention has been previously made, as contained in the above patent. One of the principal features of this machine, both in its original and its modified form, and by means of which the movements of the carriage were regulated, consisted in a pair of cones, of which the driven cone was fitted with internal gearing in communication with the loose central shaft; the respective diameters of these cones and the wheels being so proportioned, that when the driving-strap was placed in a certain position, say in the middle of the two cones, the central shaft remained stationary; whilst on moving the strap to one side of that position, the central shaft turned in one direction, and on moving it to the opposite side, the said shaft turned in the opposite direction; the number of revolutions of the central shaft increasing, in each case, as the strap was moved nearer to the end of the cone. It is evident that a change of motion could thus be effected gradually and gently, which is a feature of great importance in spinning machinery. In the machine under consideration the drawing out and putting up of the carriage, and the afterdraft were controlled by this central shaft.

The whole of the machines described in the above Patent, with

the exception only of the one last mentioned, were actually made and tried; although for various reasons, which it would be out of place here to specify, they were not adopted.

As it now became necessary to furnish the new workshops with suitable machine-tools; and, as in Mr. Bodmer's opinion, the lathes, planing-machines, and other tools which were to be had at that period were not sufficiently strong, accurate, and convenient, he set himself the task of designing a variety of tools, some of which were completely novel, whilst others, in principle already known, were by him improved, and new features of usefulness added to them. A patent taken out in 1839, and entitled, "Certain Improvements in Machinery, Tools, or Apparatus for Cutting, Planing, Turning, Drilling, and Rolling Metal and other Substances" (No. 8,070), embodied the improvements above referred to. Gradually, nearly the whole of these tools were actually constructed and set to work. The small lathes, the large lathes, and the planing, drilling, and slotting-machines were systematically arranged in rows, according to a carefully-prepared plan; the large lathes being provided, overhead, with small travelling-cranes, fitted with pulley-blocks, for the purpose of enabling the workmen more economically and conveniently to set the articles to be operated upon in the lathes, and to remove them after being finished. Small cranes were also erected in sufficient numbers within easy reach of the planing-machines, &c.; besides which several lines of rails traversed the shop from end to end, for the easy conveyance on trucks of the parts of machinery to be operated upon. Such arrangements were not common in those days, whatever may be the case now.

With regard to the wheel-cutting machine, which was an efficient and accurate, as well as a larger and more complete machine than those generally employed for this purpose in 1839, it will be proper to mention, in this place, that Mr. Bodmer had, for years, been in the habit of tracing the shape of the teeth of wheels by means of two segments of wood, representing respectively the pitch lines of the two wheels which were to gear into each other. To these segments pieces of tin plate, on which the pitch line, thickness and height of the intended tooth were marked, were fixed by tacks or screws; when the upper and lower curves were successively traced by means of an adjustable style, by rolling the circumferences of the two segments against each other. This system was pursued equally with regard to the teeth of spur-wheels, bevel-wheels, worm-and-worm-wheels, and racks and pinions, and with the most satisfactory results, as the wheels so constructed, whether on a large or on a small scale, worked noiselessly and smoothly, and with a minimum wear and tear. It is believed that this system is now almost universally adopted, although when Mr. Bodmer came to England, in 1824, it was quite unknown.

Mr. Bodmer approved so highly of the French metrical system of measures, that he adopted it, and made use of it in all his drawings and constructions. He also, from the first, introduced it into his workshops in England; and so far from experiencing any difficulties in this matter, on the part of the men, they understood it immediately, and liked it, at least, as much as the duodecimal system represented by the old foot-rule, and the subdivision of the inch into 'eighths,' 'sixteenths,' and 'thirty-seconds.' A number of wooden staves of half a metre in length, accurately marked and divided by a machine made expressly for that purpose, into decimetres, centimetres, and millimetres, were distributed amongst the workmen; and although they would frequently, by way of abbreviation, call a 'millimetre' a 'metre,' the misnomer did not lead to any errors. For the use of the pattern-makers, the measuring staves were divided so as to include an allowance for the contraction of the metal; that allowance never being left dependent upon the private judgment of the men. Besides, there was in existence, and accessible to the workmen on application to the foreman, a complete system of distinctly marked and accurately executed internal and external gauges of various kinds, so that any required measure could be tested, either directly, or by means of the callipers, if required.

Based upon the metrical system of measures, Mr. Bodmer had long ago adopted a denomination of the pitches of wheels, which differed materially from the denominations in use elsewhere. Instead of calling the distance between the centres of any two teeth on the pitch line, the 'pitch,' from which the diameter of the wheel could be ascertained, by multiplying the number of teeth with the pitch, and subsequently dividing by 3·1416, Mr. Bodmer called his pitches I., II., III., IV., &c.; and the number of teeth, multiplied by this pitch, gave at once the diameter of the wheel in millimetres. For instance, the diameter of a wheel IV. pitch, with thirty feet, was $4 \times 30 = 120$ millimetres; and the actual distance between the centres of any two teeth, on the pitch line, would, of course, be $4 \times 3{\cdot}1416 = 12{\cdot}57$ millimetres nearly, or about $\frac{1}{2}$ inch. This system possesses the great advantage, that the diameter of the wheel can be immediately ascertained from the number of the teeth, by means of simple multiplication, and that it has never to be expressed in any fractional part of a millimetre. It is now called, it is believed, the 'Manchester Pitch,' though it has only become so since Mr. Bodmer was in Manchester.

With a view to the greater uniformity, accuracy, and rapidity of execution of the work, both in the drawing-office and in the workshops, Mr. Bodmer had a number of tables prepared, which represented, both graphically and descriptively, the shape, dimensions, and particulars of the screwing-stocks, dies, and taps, and wrenches: of the

heads and nuts of screws and bolts for various purposes; of screw-keys of various kinds; of the keys required for keying wheels and pulleys on shafts; of the drills and boring tools for various purposes; of the pedestals and brasses for various sizes of shafts, &c. After the general drawing of any machine had been made, the parts for which patterns were required, and those which had to be made in the smiths' shop, were drawn out on separate sheets of paper, with all the dimensions accurately marked in millimetres. These drawings, upon being completed, were mounted on pasteboard, varnished, and afterwards given into the hands of the respective foremen. After the smiths and pattern-makers had done their part, the drawings were passed into the turning and fitting-up shops, together with the general drawing. The whole of the drawings were numbered consecutively, and these numbers, with description, were entered in a book kept for that purpose.

The pentagraph had never, previous to the date of Mr. Bodmer's patent, been applied, it is thought, as a shaping and cutting tool for metal; a few observations respecting its construction and functions may, therefore, not be out of place. It was intended for turning, shaping, and grooving cutters, to be used in cutting the teeth of metal wheels; and it effected these operations with great facility and accuracy, by means of a guide and template on an enlarged scale, which latter determined the shape of the cutter, as fixed to the spindle of a headstock through the instrumentality of stationary and rotating cutting tools respectively. In order to admit of the construction of cutters of comparatively large dimensions, without running the risk of their warping or breaking in the hardening, they were each composed of six equal segments, made with projections to form a boss about the centre, to be grasped by two box-rings; one of which formed part of the spindle for holding the cutter, whilst the other was removable, and could be tightened up against the cutter by means of a nut. The pentagraph headstock was so arranged, that, after the cutter had first been bored, turned, faced, and roughly shaped on the lathe, the exact contour could be given to it on the pentagraph by allowing the spindle, with the cutter mounted on it, to revolve, whereupon a small tool, with a conically-shaped head, and connected with the short limb of the pentagraph, was brought into action against the cutter. This operation, having been accomplished, the headstock spindle was connected with a dividing apparatus, by means of which, and by causing a conically-shaped and milled tool of precisely the same dimensions as the one above mentioned, but revolving rapidly instead of being stationary, to act upon the cutter under operation; the latter was, at suitable and equal distances, provided with the requisite grooves. The finished cutter was, thereupon, marked with the number of pitch, &c., and subsequently hardened, each segment

by itself, in which process oil was used for the purpose of obtaining a uniform temper. By means of such cutters the whole of the change wheel patterns were cut; and for whatever other purposes cutters might be wanted, as, for instance, for shaping nuts, for cutting grooves, in screwing taps or otherwise, they were made in precisely the same manner: the enlarged template, previously referred to, insuring, of course, great accuracy and uniformity as to shape. There was also an apparatus connected with the pentagraph by means of which screw-cutters for cutting worm-wheels could be shaped; and many such, of beautiful workmanship and great efficiency, were so made.

Another machine which deserves particular mention, was the 'Circular Planing Machine,' in all respects similar to the ordinary planing machine, except that it had a circular horizontal table, which revolved in V grooves on a cylindrically-shaped bed, besides being supported by a vertical spindle, by means of which it could be raised out of contact with the grooves, and thus caused to revolve at an increased velocity. This machine was used for planing or turning heavy wheels, as well as for boring them, being likewise provided with a self-acting boring bar, which could be placed in and out of gear, at pleasure. This convenient machine-tool was, however, equally well adapted for facing the ends of steam-engine cylinders, and for operating upon other articles too inconvenient in shape to be dealt with by a lathe, or ordinary planing machine.

The grinding, equalising, or polishing machines, of which several were in operation at Mr. Bodmer's workshops, were of great service in all cases where any surfaces, whether flat or cylindrical, had to be equalized and polished. A machine of this description, fitted with a copper disc of about 3 feet in diameter, mounted on a horizontal spindle, and revolving at a great velocity, was, for a considerable time, chiefly employed in operating upon rollers or cylinders of 10 inches in diameter, and 15 inches in length, which were required by Messrs. Macintosh and Co. in the preparation of India-rubber. These rollers were made of cast iron, chilled; and it was absolutely necessary that they should be, throughout, of precisely the same diameter, and that their surfaces should be perfectly true and smooth; and the result was invariably all that could be desired. In connection with these rollers, it may here be mentioned that Mr. Bodmer made the plans and drawings for, and executed at his works, a whole series of machinery for the preparation of caoutchouc, to the order of Messrs. Macintosh and Co.

Another machine of the same kind, but fitted with a copper disc mounted on a vertical spindle, was used in operating upon the surfaces of lathe beds or other metal surfaces, with a view to the usual scraping being dispensed with. In this machine the bearings of the spindle were held by a radial arm, which was both horizon-

tally and vertically moveable and adjustable, whilst a vibrating motion was communicated to the table upon which the object to be operated upon was placed. The disc of the above first-mentioned machine, however, was mounted on a slide, horizontally adjustable on a suitable bed, and the article to be equalized was also mounted on slides, whereby it could be moved both horizontally and vertically, and brought closer to or removed further from the disc. In the case of rollers or cylinders, they were mounted on the slide in bearings, and a rotatory motion could be imparted to them. Besides these special machines a variety of smaller discs, mounted either on slide rests or on independent frames, were used, for 'bracing up' case-hardened spindles, journals of shafts, cylindrical case-hardened gauges, and for other purposes, in every case proving most useful and valuable auxiliaries.

With regard to the mills for rolling tires for wheels and hoops for boilers, which stand last in the list of inventions contained in the Patent of 1839, it may be as well to observe in this place, although the transactions to be referred to occurred many years later (about 1845), that both Mr. Birley and Mr. Bodmer gave themselves much trouble in endeavouring to induce some manufacturers of iron, who were at the time in the habit of supplying tire-bars to the makers of railway rolling stock, or some of these makers themselves, to give the tire rolling mill a trial. Accurate and expensive working models were prepared, and tires of lead actually rolled in them, so as to give a clear idea of the working of the machine; and it was explained what a great saving in material would be effected, owing to the fact that such tires would require no subsequent turning on the lathe; that, in the case of engine tires, certainly, the rolling would involve much less expense than the turning, and that finally the tires would be more durable, on account of the harder skin left by the rolls. But it was impossible to overcome the prejudices of ironmasters and engineers by any such arguments. At last Mr. Peter Rothwell Jackson, of Bolton, who had entertained a favourable opinion of the invention from the time when his attention was first directed to it, decided upon taking a licence from Mr. Bodmer, in conjunction with Mr. James Hardcastle, of Firwood. Mr. Jackson and Mr. Hardcastle accordingly erected, in Salford, near Manchester, a tire rolling mill embodying, in substance, various improvements secured by Mr. Bodmer in two subsequent patents. Many practical difficulties had to be overcome before the manufacture of the tires could be systematically and economically carried out: and after that it required great perseverance, much reasoning, and a vast accumulation of facts, before contractors and railway companies could, except in isolated instances, be induced to use the rolled tires. After a short time Mr. Hardcastle retired, and left the business altogether in Mr. Jackson's hands. The latter, on the

expiration of the Patent of 1839, in 1853, through Mr. Thos. H. Birley, the son of the late Mr. Hugh Hornby Birley, applied for, and obtained a prolongation; but previously to that time he had, and he has since then obtained several patents for improvements made for himself in tire rolling mills. The opinions of railway engineers, contractors, and others in the habit of using tires, have since undergone such a remarkable change, that tire rolling mills have now sprung up all over the country. Until very recently no attempt has been made to carry out the rolling of hoops for boilers; but there can be no doubt that this second branch of the invention will, in the end, prove as important as the first.

At Mr. Jackson's works the rolling-mill was driven by a non-condensing high-pressure steam-engine of 30 H.P., constructed upon the inverted cylinder compensating or double piston principle. These engines are described in Mr. Bodmer's Patent No. 8,981, of 1841, and they have, as their name implies, the crank-shaft mounted in bearings fixed to the frame or sole plate. A certain number of engines of this kind, some being of 8 H.P., some of 30 H.P., and some of 60 H.P., were made at various times and set to work: the 60 H.P. engines chiefly at some of the bleach-works near Bolton; but one of them, as well as one of 30 H.P., at the works of Messrs. Macintosh & Co. A 30 H.P. condensing engine was also erected at the works of Messrs. Sharp, Roberts, & Co., and intended to drive the tools, &c., forming part of a recent extension of their establishment. The crank-shafts of these steam-engines were made of cast iron, and the foundations consisted of a few feet of brickwork, the sole-plate resting upon stone slabs. The speed of the 60 H.P. engines was about one hundred and twenty revolutions per minute, and it was constantly maintained, without the least inconvenience or difficulty. One of these engines, erected at the bleachworks of Mr. Horridge, near Bolton, was regulated by a governor acting upon a throttle-valve in the exhaust-pipe, which prevented the egress of the steam, and therefore instantaneously checked the speed of the engine. This governor was described in a Patent of Mr. Bodmer's, No. 10,243 of 1844; but it was afterwards found that, in principle, it had been known before.

As Mr. Bodmer's partially successful efforts to introduce his compensating or double-piston steam-engines at bleachworks have been referred to, it may be mentioned that Mr. Bodmer had, previously to 1833, already invented, in connection with some of his improved cotton machinery, a simple and efficient apparatus for connecting and disconnecting machinery with the driving-shaft, without producing those sudden shocks which were unavoidable with the clutch-boxes and other similar contrivances then in use.

Several improvements upon this primitive apparatus, adapting it for use in connection with the most powerful machinery, were patented by Mr. Bodmer in 1843 and 1844 (Patents Nos. 9,702 and 10,243) respectively; and as it appeared particularly desirable that the action of the mechanism for stopping and starting bleachers' 'mangles' and callenders should be perfectly smooth, Mr. Bodmer recommended his Patent Starting Apparatus, or Break, as it was generally called, to Mr. Thomas Ridgway Bridson, of Bolton, who at once consented to have it introduced at his bleach-works, where one of the 60 H.P. compensating engines was already at work. It answered its purpose remarkably well, in connection with one of the large mangles, enabling the attendant to stop and start the machine at the precise time required, without the least damage to the goods under operation, and without any noise whatever. In the apparatus here referred to the desired effect was produced by tightening or releasing a strap, which acted as a friction break upon the external circumference of an internal wheel, which latter was connected by other wheels both with the motor and with the machine to be set in motion and controlled. In other cases the Starting Apparatus acted simply through the friction between a number of segments, connected with a sleeve by means of togglejoints, and lined with copper, against an internal drum mounted upon a shaft in connection with the motor: the sleeve or sliding bush being mounted upon the shaft to be set in motion and disengaged, as might be required. Starting Apparatus of both kinds, and which, owing to their peculiar construction, would, in case of the machines connected with them meeting with undue resistance, yield to the force applied by the motor, were subsequently also adopted by Mr. Horridge and others. In some of the bleachers' mangles which Mr. Bodmer constructed at his works he introduced self-adjusting bearings of superior hardness; but the principal improvement consisted in making the brass 'bowls' of a superior kind of alloy. These bowls, after having been 'roughed out' on the lathe, to nearly the finished size, were submitted to the operation of a narrow milling tool, which, being placed in the slide-rest, was made to pass along the whole length of the bowl, strongly compressing the metal on its surface, whereupon the finishing cut was given. Bowls so treated proved more efficient and durable than those in common use.

Mr. Bridson consented, at Mr. Bodmer's request, to let three steam-boilers be fitted with the improved firegrates which Mr. Bodmer had patented in 1843 (Patent No. 9,899). In these grates the firebars were actuated by screws, similarly to the 'gill bars' of flax-machines. These screws, made of cast iron, were placed in suitable frames and bearings underneath and at a suitable distance from the boiler, as much as possible out of reach

of the fierce heat of the fire, and connected by means of worms and wormwheels, or other gearing, by which they were caused to revolve in opposite directions, propelling the firebars towards the bridge. Arrived there the bars were, by a suitable apparatus, guided down into the threads of the lower or return screws, and on arriving in front, each bar was, in succession, once more raised to the level and under the action of the top screws. A hopper, fitted with an adjustable sliding door, was placed over the firebars, in front; and as the firebars moved slowly towards the bridge, the fuel, descending from the hopper, was of course compelled to move with them, covering the bars to the depth corresponding with the opening of the sliding door. The top screws were, however, so constructed that near, and to some distance from the hopper, in the direction of the bridge, up to which point the fuel must be supposed not to have become as yet fully ignited, the firebars lay very close together, so as to prevent the small coal from falling through; whilst from that point onwards the threads of the screw became more and more 'drunken' and further apart, thus causing the firebars to rock backwards and forwards, and any clinkers that might have formed upon them to break off (if not preventing the formation of clinkers altogether), and, besides, admitting a greater body of air for the support of the combustion. The threads of the screws then gradually returned to their regular shape again, and at that distance from the bridge where the fuel might be supposed to have become to a great extent consumed, the distance between the bars was once more contracted. It was at first found almost impossible to keep the fuel in a state of ignition near the firedoor; but this defect was completely remedied by arching over the entrance to the furnace with firebricks. These grates answered very well in principle, as, besides admitting of the utmost regularity of firing, with which operation the fireman could not interfere, and which prevented the formation of smoke almost altogether, the smallest slack could be used with advantage. Upon testing one of these screw firegrates, in its usual working state, against a common grate fitted to an adjoining boiler of precisely the same dimensions, it was found that by burning large coal in the latter, and using every possible precaution as to the closing of dampers, keeping a thin layer of coal upon the bars, cleaning the spaces between the latter, &c., which under ordinary circumstances it would never have occurred to the fireman to observe, the two grates were about equally effective; almost identically the same quantity of water being evaporated in each with a given weight of fuel. But as the screws, although protected, as has been observed, as much as possible, were still exposed to a great degree of heat, which precluded the use of lubricants, both the screws and the bars wore out rapidly; and after this wear and

tear had once proceeded to a certain extent, the bars became displaced, got jammed in between the threads of the screws, and then broke. It also, sometimes, happened, that between the Saturday evening and the Monday morning following a piece of iron or stone got accidentally mixed with the coals, which substances the grates were not calculated to deal with; and on such occasions a break-down would naturally occur. As the firebars, during their return from the back to the front, had time to cool, being exposed to a strong draft of air for a considerable time; and as, moreover, not one of the bars was constantly subjected to an intense degree of heat, they had not often to be changed or replaced by new ones.

In 1841 Mr. Bodmer took out a patent (No. 8,912) for "Certain Improvements in the construction of Screwing Stocks, Taps, and Dies, and certain other Tools or Apparatus or Machinery for cutting and working in Metals." As will be seen from the annexed Schedule, the Screwing Stocks, Taps, and Dies constituted one of the principal features of this Patent. In order to constitute the die a real cutting tool, and thereby to render it effective with a smaller expenditure of power, as well as to avoid the elongation of the screw which generally occurs when ordinary dies are used, Mr. Bodmer conceived the idea of giving to the die a very small but sufficient amount of lateral play; so that, whether it were acting from above downwards, or from below upwards, it should at all times present a real cutting edge to the screw under operation; thus avoiding all unnecessary friction, and leaving space for the shavings (in this case real shavings) to detach themselves without interfering with the action of the tool. With the purpose of attaining a similar result in regard to the taps, Mr. Bodmer, instead of merely 'backing off' the external circumference of the screw-thread, conceived the idea of relieving each cutting segment of the tap in such a manner as to make the section of each segment, at its largest diameter, the cutting edge, the remaining portion acting merely as a guide. This was accomplished by means of a lathe expressly constructed for the purpose, and in which the motion of the slide-rest, holding the tool, was regulated by a template representing the section of the tap on an enlarged scale. To save trouble the diameter of the circle circumscribing the six-sided heads of these taps was made to correspond with the internal diameter of the tap, so that it could be dropped through the nut after the cut had been accomplished. Screwing stocks, taps, and dies of this description were in constant use at Mr. Bodmer's workshops, and were found to work freely and accurately. Many years later, however—in fact, only a few years before his death—Mr. Bodmer made still further improvements in this description of tools—more especially in the screwing stocks—as well as in the lathe for manufacturing and shaping the taps.

The chasing tools, so that they might combine efficiency and strength, were constructed upon similar principles. Each tool consisted of a segment, adjustable and capable of being firmly fixed in a holder of corresponding shape, the handle of which could be firmly secured in the slide-rest. It could be brought to bear upon the screw to be operated upon in a manner analogous to that of the tap and the nut, and ground and re-set without any trouble, and with the greatest accuracy.

The crank lathe, fitted as it was with a peculiar kind of slide-rest for turning the journals, was found exceedingly valuable in dealing with the cranks of the compensating or double piston steam-engines. The centre chucks, in which the jaws were made to advance towards and to recede from the centre simultaneously, by means of a central wheel, actuated by the spindle of the fast headstock, in which it was recessed, and in its turn acting upon three pinions mounted upon the screws which regulated the motion of the jaws, were applied to many of the lathes, and found most useful. An improved universal joint, fitted with ball and socket as the means of admitting of a deviation from the straight line in one direction, and with strong swivel pins to render such deviation possible in the other direction, was subsequently successfully applied, as a connection between the starting apparatus, or friction breaks formerly described, and the driving bowls of bleachers' mangles. Acting upon the principle that turning is cheaper than any other kind of work, Mr. Bodmer designed a peculiar construction of the heads of the connecting-rods for his steam-engines, which consisted in turning the same externally, and boring them internally for the reception of the brasses; the straps being, of course, also bored out internally, and, after having been placed in their proper position, turned externally. For this internal turning, or boring, a tool was purposely constructed and claimed in the same Patent, by means of which these operations could be performed accurately and expeditiously.

The whole of the tools enumerated in the annexed schedule, referring to the subject-matter of this Patent No. 8,912, with the exception only of the large slotting-machine, with circular table, and the apparatus for rectifying screws, were actually made and used in Mr. Bodmer's works, and were found to answer their purpose remarkably well. Besides these, however, a large radial boring-machine, and a wheel-cutting machine capable of taking in wheels of 15 feet diameter, and of splendid workmanship, especially in regard to the dividing wheel, and a number of useful break or gap-lathes, were also constructed and used with advantage. It is especially necessary to mention a number of small, 6-inch, screwing lathes, which by means of a treadle acting upon the driving-gear

overhead, and a double slide-rest—one of the tools moving into cut as the other was withdrawn,—screw cutting could uninterruptedly proceed both in the forward and in the backward motion of the toolslide, and therefore a given amount of work accomplished in half the time which it would occupy by the use of the ordinary means. Some of the slide-lathes were also arranged for taking simultaneously a roughing and a finishing cut.

It was likewise in 1841 that Mr. Bodmer took out a patent for "Certain improvements in Machinery for Propelling Vessels on Water, parts of which improvements apply also to Steam-engines to be employed on Land."—Patent No. 8,981. One portion of these improvements refers to a peculiar kind of propeller, consisting, in the main, of a fan revolving in a box; into which latter the water can penetrate through its own gravity, in proportion as it is expelled by the rapid revolutions of the fan, through a short channel, leading from the aforesaid box, horizontally or nearly so, into the water, both ahead and astern of the vessel to which this kind of propeller is applied. These channels were to be fitted with slides or valves, capable of being regulated at pleasure from the deck, by means of hand-spoke wheels and suitable gearing, so as to exclude the water either from the one or from the other, or to contract the openings of either one or both of them, according as it might be desirable to go ahead or astern, to moderate the speed of the vessel in either direction, or to turn the vessel completely round. All this could be accomplished without interfering with the engines, which were to be of the compensating, or double piston principle. Two such fans would be required for each vessel, one to be placed on the port side and the other on the starboard side. Improvements upon these fan-propellers were further secured by Mr. Bodmer in his Patents of 1843 and 1844 respectively (Nos. 9,702 and 10,243); their application to a life-boat being shown in the specification of the former patent. A pair of propellers, with compensating engines, was constructed upon the principle of those represented as applied to the life-boat; the distinctive features of which are that, by simply turning the cylindrical fan-box round its axis, which can be done at pleasure from the deck, the vessel could not only be propelled ahead and astern, but be completely and efficiently steered. One of these fans, with box complete, was placed on a large water-tank, and caused to rotate by means of its own engine; and to judge from the force of the out-rushing stream upon the surrounding water, the effort, if applied to propulsion, must have been satisfactory. Mr. Bodmer was, however, unable to test the apparatus as a propeller; and it was left to Mr. Ruthven to prove, twenty years later, that this kind of propulsion can be carried out in practice. It would nevertheless appear, from the records of the Patent

Office, that fan-propellers and moveable fan-boxes for directing the stream or current of water produced were known previously to the date of Mr. Bodmer's patent.

Recurring again to the Patent No. 8,981, it becomes necessary to mention Mr. Bodmer's Expansion Apparatus, the principal features of which consisted in the expansion-valve rod having a right and a left-handed screw cut upon it, on which the expansion valves—whose position was on the back of the slide-valves—could, by means of nuts forming part of, or attached to them, be made to recede from or to approach each other; thus cutting the steam off at an earlier or at a later part of the stroke. Further improvements in, and modifications of this system of expansion-gear were patented by Mr. Bodmer in 1843 (Patent No. 9,547), and in 1844 (Patent No. 10,243). Mr. Bodmer applied expansion-valves, constructed upon this principle, to all his compensating or double-piston engines; and after the invention had been patented once more by a Mr. Meyer, of Mulhausen, in France, it was adopted by Messrs. Sharp, Brothers and Co., of Manchester, who applied the valves to some locomotive engines, but in a short time abandoned their use, finding them too complicated. On the occasion of this right and left hand screw-expansion valve-regulating apparatus being patented a third time, some years ago, and published as a novelty in one of the scientific periodicals, it was stated, by a correspondent of that journal, that it was then very generally in use in Lancashire; but Mr. Bodmer's name was not mentioned in connection with it; and his expansion gear was also applied to the engines of H. M. Screw Steam Ship 'Amphion' without acknowledgment.[1] In France and on the Continent generally it is known as Meyer's Expansion gear.

Mr. Bodmer contributed two Papers, illustrated by drawings and models, to The Institution of Civil Engineers, during the Presidency of Sir John Rennie, one on "The Advantages of Working Stationary and Marine Engines with High-pressure Steam, expansively and at great velocities; and of the Compensating, or Double Crank System,"[2] for which he received a Premium,[3] and in which communication a description is given of his "Variable Expansion Gear;" and the other, "On the Combustion of Fuel in Furnaces and Steam-boilers, with a description of Bodmer's Fire-grate."[4]

In the Patent No. 8,981, of 1841, and again in the Patent No. 9,702, of 1843, Mr. Bodmer has shown numerous methods of jointing the plates, in the construction of iron ships, in such a manner as to insure, in the first place, perfect uniformity of surface, and in the next place, to increase the strength of the hull.

[1] *Vide* "The Artizan" for 1853, vol. xi., p. 15.
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. iv., p. 372.
[3] *Ibid.*, vol. v., p. 2.
[4] *Ibid.*, vol. v., p. 362.

After having shown the application of his compensating, or double-piston principle to locomotive engines, in his Patent of 1834 (No. 6,616), Mr. Bodmer, in his Patent No. 8,981, of 1841, claims various improvements, which consist, principally, in a peculiar construction of the frame; in the application of spherically-shaped brasses to the ends of connecting-rods; in the use of spherically-shaped axle bearings, and in modifications of the hand gear. Longitudinal sleepers with cylindrico-convex bases, to support broad rails, with a soft elastic substance interposed between the rail and the sleeper, and a broad locomotive engine-wheel tire to run upon such rails, are also described. Further improvements, applying chiefly to the expansion gear, hand-gear, pistons and axle-boxes of locomotive engines, were patented in 1843 (No. 9,702); the axle-boxes being constructed for lubrication with oil, and upon the principle of the ball-and-socket joint, so as to cause them to yield to the unevenness of the road, without binding. The tender is, in this patent, represented with a break which can be made to bear simultaneously upon the wheel and the rail. Again, in Mr. Bodmer's Patent No. 10,243, of 1844, various improvements in locomotive engines and tenders are described and claimed. As regards the locomotive engine, they related to the construction of the fire-box, in which partitions of brass were applied; to the rocking motion of the fire-bars; to the use of four cylinders, two inside and two outside the framing, the former acting upon the crank-axle, and the latter upon crank-pins, and worked by the same slide and expansion-valve; to a peculiar combination of coupling-rods; to the adaptation of air-pumps for injecting air into the boiler; to the construction of brass locomotive engine wheels; to the application of hollow brass piston-rods, &c. As regards the tender, the improvements referred to the feeding of the locomotive engine boiler by pumps placed on and worked by the wheels of the tender, and to the converting of the drag links between the engine and the tender into tubes for conveying the feed-water to the boiler.

Between 1844 and 1846, two locomotive engines, constructed upon the double-piston or compensating principle, and containing many of the improvements above enumerated, as well as two tenders fitted with feed-pumps and skid breaks, were made for and supplied to the South Eastern railway company. These engines were found, on trial, to get up their speed in a remarkably short space of time, and to run without any lateral, oscillatory, vibrating or longitudinal reciprocating motion. But after they, and especially the tenders, had been subjected to a number of alterations, they were, for no assigned cause, withdrawn from the line.

A patent secured by Mr. Bodmer in 1842 (No. 9,279) contained further improvements in the construction of cotton machinery, as enumerated in the annexed Schedule. Another patent, of the same

year (No. 9,279), already alluded to, contained chiefly modifications of the rolling mills for tires, as well as for pulleys and other hoops. The improvements comprised in Patent No. 9,702, of 1843, have already been alluded to. A pumping-engine upon the double-piston principle was made to order; but afterwards, owing to a misunderstanding, countermanded and never tried.

With the exception of an independent or portable boiler, fitted with the screw fire-grate, and the lathe for cutting the 'drunken' screws, the inventions described in Mr. Bodmer's Patent No. 9,899, of 1843, were never carried out. But it deserves to be mentioned that the band-saw, which has since come into such general use, and a license for the manufacture of which was, some years ago, sold for a considerable sum of money by a second inventor, was claimed in the above-named Patent.

About the year 1846—after the death of Mr. Hugh Hornby Birley, who with the utmost liberality had provided the means for the carrying out of these inventions—Mr. Bodmer went to London, where his time was chiefly occupied in devising further improvements in the construction of machine tools, locomotive and other steam-engines, and artillery. He left London in 1848 for Vienna, where, in the year following, he was in some respects a highly interested, but rather exposed spectator, from the top of the house in which he had taken up his quarters, of the operations of the Austrian troops against the insurgent citizens. The Soemmering railway was about that time being constructed, and Mr. Bodmer, for a considerable period, made it his especial study to design locomotive machinery, adapted for conveying heavy loads at moderate speeds up and down steep inclines, with safety and economy. After his plans had been sufficiently matured, he put himself in communication with the Directors, but was not successful in inducing the Directors to sanction the adoption of these plans. Mr. Bodmer, subsequently, for a considerable period devoted much of his time to the improvement of the process of the manufacture of beet-root sugar, and gradually designed a novel system of machinery. He was also actively engaged, at times, in working out a new system of Ordnance projectiles, and was in treaty both with the Austrian and the Russian Governments for its adoption. He likewise submitted some of his improvements, as applied to guns of ordinary construction, and an apparatus for bouching cannon in the field, to the Committee appointed to examine and report upon such matters in England, in 1857.

After a few years' residence in Vienna, Mr. Bodmer settled for a time at Lanzendorf, a village situated at a distance of a few miles from Vienna, on the Vienna-Raab railway, where a friend of his was the proprietor of a manufactory of railway wheels, axles, and other objects connected with railway rolling stock, as well as brass boiler

tubes. Mr. Bodmer here made further improvements in steam-engines, boilers, and fire-grates, and also invented an improved safety-valve for steam-boilers; an apparatus for preventing incrustations in steam-boilers; an apparatus and pump for maintaining at all times the same water level in steam-boilers; an improved blow-off cock, an improved water-gauge, two improved governors for steam-engines, an improved water-meter, an improved gas-meter, and a variety of other things. A steam-engine upon Mr. Bodmer's compensating principle, but in which there was only one piston, the cylinder doing duty as the second piston, and both the cylinder and the piston being connected with the same crank, —was constructed, worked, and experimented upon, in connection with a boiler and fire-grate of the improved kind.

About the year 1860, Mr. Bodmer returned to his native town of Zurich, and took up his residence with his son-in-law, Mr. Frederick Reishauer. He was there at first, and for a considerable time, engaged in perfecting his system of breech-loading cannon and projectiles, as also a breech-loading rifle. A cannon on a small scale, and a rifle of the kind alluded to were actually made; and experiments were tried which showed that, although the projectile of the cannon left much to be desired, the mode of locking the breech answered its purpose very well, being free from the serious objections which generally attach to this part of a breech-loading cannon. Subsequently, and amongst a variety of other things, Mr. Bodmer still further improved his system of screwing-stocks, taps, and dies, and the machinery for producing the same.

When young, Mr. Bodmer's activity and endurance knew scarcely any limits; and even in later years he was in the habit of beginning his day's work at five o'clock in the morning; and in fact continued to do so up to within a few months of his death, being engaged in drawing or writing all day, and sometimes far into the night. Mr. Bodmer was elected a Member of The Institution of Civil Engineers on the 15th of February, 1835. He died of a dropsical complaint on the 29th of May, 1864, in the 79th year of his age.

Schedule of Inventions contained in Mr. J. G. Bodmer's several Patents.

No. 6,616, of 1834.

1. Double Piston on Compensating principle, shown as applied to Locomotive Steam Engines.—Apparatus for counteracting the pressure of steam upon the Slide Valve by means of pistons.—Double crank-shaft Bearings and compensating Springs.—Segment Guides for Bearings of crankshaft.—Convex spherically-shaped Axle-bearings. —Three modifications of expanding metallic Packing-rings for Pistons.—Self-acting Lubricating Apparatus.—Hollow Piston-rod.

—Mechanism for increasing speed of Driving-wheel independently of that of Engine.

2. Safety Valves. — Draft-Regulating Apparatus. — Mode of producing Draft when the Engine is not running.—Feed-water Heating Apparatus in Smoke-box.—Slanting Fire-grate.—Three modifications of Boilers.

No. 6,617, of 1834.

1. Revolving Drum Fire-grate.
2. Travelling or Propelling Grate, with Fire-bars in Sets.
3. Chain-Grate.
4. Vibrating or Rocking Grate.
5. Application of Propelling Grate to Puddling Furnaces and Brewers' Coppers.
6. Application of Propelling Grate to Hot-air Stoves and Singeing Stoves. —Triple Boiler.—Boiler fitted with Tubes and Chambers placed over Grate and Fire-bars.

No. 6,841, of 1835.

1. Feeding Plate, applied to Willow Machine and Carding Engine.
2. Two modifications of Self-acting Topcard Stripping or Cleaning Apparatus.
3. Arrangement for stopping and starting the Feeding and Doffing Apparatus of a row of Carding Engines, without suspending the operation of the Main Drum.—Mode of conducting Slivers through Spouts and between Press Rollers to Lap Machine.
4. Lapping Machine for Drawing Frame.
5. Position for Lapping Machine of Stubbing Frame, at right angles, or transversely to the Machine.—Twisting Tubes, with reciprocating motion for giving tenacity to the fibres before winding upon bobbins.—Weighted Pressing Rollers in connection with the above.—Improved mode of changing the Bobbins of Lapping Machines.—Various mechanism for imparting a reciprocating motion to the Twisting Tubes.
6. Arrangement of the Unlapping or Unwinding Rollers, as applied to the Feeding of Drawing, Slubbing, and Roving Frames.
7. Application of a system of Drawing Rollers to the Lapping Machine of Carding Engines, instead of Drawing Boxes applied to each Carding Engine.
8. Application of the above system of Drawing Rollers to the Lapping Machines of Drawing Frames.
9. Conducting the Slivers in separate compartments to the Drawing Rollers, by means of several Belts.—Mechanism for traversing and lapping Slivers upon a Bobbin.
10. Apparatus for producing Bobbins, with conical ends, and twisting the rovings.
11. Method of unlapping the Bobbins for feeding Mules and Throstles by means of Belts.

No. 7,388, of 1837.

1. Novel construction and peculiar arrangement of certain parts of the ordinary Throstle, for the purpose of effecting the winding of the yarn upon the bare spindle, in the form of Pincops.
2. Flyer or Guide, and Container, or Box connected with the above: the Flyer or Guide being independent of the Spindle, and acting by virtue of its centrifugal force, when linked to the thread.
3. Apparatus for sizing and preparing yarn in its passage from the rollers to the spindle.

4. Application of two rows of spindles in one Mule carriage, and thereby effecting the 'putting up,' or 'winding on' of the yarn upon one row of spindles, at the same time as the 'stretch' or spinning process is performed upon the other row.

No. 7,837, of 1838.

1. Two modifications of Apparatus for stripping Topcards.
2. Apparatus for stripping or cleaning Main Drum.
3. Self-acting Apparatus for grinding Topcards.
4. Various modifications of Feeding Knife.
5. Lapping Machine for winding a single Sliver or Band on to one Bobbin by means of a right and left-hand Screw-Scroll.
6. Lapping Machine for changing Bobbins expeditiously, by means of a handle and gearing.
7. Machine for winding the Sliver of a Carding Engine layer upon layer, in the shape of a Coil.
8. Coil Machine for the Band of a Drawing Frame.
9. Coil Machine with Twisting motion, for Roving Frames.
10. Two modifications of Apparatus for producing a reciprocating Twisting motion.
11. Independent Spinning Machine.—Application of Differential cones to produce the various motions of the carriage, &c.

No. 8,070, of 1839.

1. Wheel-cutting Engine, for cutting external and internal Spurwheels, Racks, and Bevel-Wheels of Wood and Iron—with adjustable Table.
2. Segmental Cutters.
3. Pentagraph, adapted for shaping Cutters for Spur and Worm-wheels, and for other purposes.
4. Machine for grinding spherical Lenses.
5. Machine for equalizing and polishing large and small feet or cylindrical surfaces, by means of copper discs mounted on slides, and revolving at great velocities.
6. Loose Headstock for Lathes.—Spindle bearing throughout its length.
7. Guiding and adjustable Boring Tool.
8. Expanding Mandril.
9. Planing Machine.—Double Tool Slide, with self-acting apparatus to move out of cut, and moveable vertically, horizontally and about the centre.
10. Planing Machine with moveable bed outside, and independent of Tool Slides, for vertical and horizontal cut.—Tool Slides as above.
11. Hand-Planing Machine, worked by contact pulleys.
12. Planing Machine with adjusting Table, moving on Pivot, for cutting polygonal articles.
13. Nut-cutting Machine, for cutting two sides of a row of Nuts, placed on a mandril, simultaneously; fitted with dividing apparatus.
14. Circular Planing Machine, for turning, planing, and boring large wheels, or other parts of machinery.
15. Differential Double Screw Slide-lathe, for turning Cones, rounding the surfaces of pulleys, turning Ball-sockets, and Balls, and cutting Screws of any desired pitch.—Apparatus for moving Slide separately from Screw.—Apparatus for moving Tool in and out of cut quickly.
16. Apparatus for cutting Nuts on Lathe.—Nut-cutting Bar, for cutting Nuts of large size.
17. Drilling Machine with differential Feeding Apparatus.

18. Slotting Machine or Key-grooving Machine, fitted with Apparatus for taking Tool out of cut in the upstroke.—Tool Slide adjustable for cutting at angles.
19. Tapping and Screwing Machine.
20. Novel arrangement for securing Cutters in Connecting-rod ends and Straps, by means of a set-screw.
21. Rolling Mill for rolling Tires for Railway and other Wheels to their finished shape and size; so as to dispense with any further operations.
22. Rolling Mill for rolling Hoops for Boilers.—Various modes of jointing such Hoops with flush joints.

No. 8,912, of 1841.

1. Lathe for turning Crank Axles, fitted with two-face plates driven simultaneously from a horizontal shaft, by means of pinions, gearing into the toothed circumferences of the face-plates: the face-plates being fitted with adjustable bearings, which can be set to any desired distance from the centre, according to a scale marked thereon.
2. Universal Joint; in which the ball and socket, and the swivel principle are combined in such a manner as to increase the strength of the mechanism, without prejudice to its efficiency.
3. Connecting-rod Head.—Connecting-rod End turned cylindrically, and bored out spherically for the brasses.—Strap bored out internally and turned externally.
4. Tool for boring out Connecting-rod Straps.
5. Tool for turning Spheres.
6. Screwing-Stock with moveable Cutting Die.
7. Tap for cutting internal Screws; thread 'backed off' both at top and bottom: called Convolute Tap.
8. Adjustable Chasing Tool and Holder.
9. Self-acting Tap-cutting Lathe for forming Convolute Taps.
10. Apparatus for regulating or correcting Screws, by means of a Screw working in wood, and regulated by gearing.
11. Large Slotting Machine.—Tool actuated by a Screw in combination with Rack and Pinion, and brought into and out of cut by inclined planes.—Tool reversible.—Machine also adapted for cutting Grooves or Slots, like an ordinary Planing Machine.
12. Double Drilling Machine for large and small Holes, fitted with differential gearing to effect the feed, which remains uniform, however the metal under operation may vary as to its hardness or porosity.
13. Centre-Chucks for Lathes, in which the Jaws are moved simultaneously by means of a Central Wheel fixed to the Spindle of the Headstock.
14. Planing Machine worked by a Crank-motion.—Various modifications of Starting and Stopping Apparatus.
15. Planing Machine, in which the Table is actuated by means of a Worm gearing into a Rack, which is a segment of a Nut.
16. Wheel and Screw Press for forcing Mandrils into Wheels.—Also to be used as a Drifting and Trenching Machine. This machine is fitted with a short-stroke Eccentric, and the combination of mechanism is such that the Mandril or Punch is constantly in contact with the object to be operated upon.

No. 8,981, of 1841.

1. Fan-propeller, in connection with Compensating or Double Piston Steam Engine.
2. Expansion Valves, regulated by right and left Screw.

3. Pillar Steam Engine, with stationary Piston and moveable Cylinder.
4. Compensating or Double Piston Steam Engine applied to Paddle-wheel Propeller.—Paddle-wheel so constructed that the dip of the Floats can be adjusted.—Stationary shaft Paddle-wheels driven by Pinion gearing into segments.
5. Mode of jointing the Plates of Iron Ships.
6. Inverted Cylinder Stationary Compensating or Double Piston Steam Engines.
7. Locomotive Compensating or Double Piston Steam Engine.—Framing formed of timber, in layers.—Connecting-rod brasses turned spherically.—Spherical Axle-bearings.—Hand-gear.—Broad Railway-wheel Tire, in combination with flat Rail, bedded on cylindrico-concave longitudinal Sleepers, with a soft or elastic substance between Rail and Sleeper.—Oiling Apparatus.

No. 9,279, of 1842.

1. Blowing Machine for producing narrow Laps, in connection with Lapping Machine patented in 1838.
2. Self-acting Doffer Knife to Lapping Machine.
3. Improvements in self-acting Topcard Stripping or Cleaning Apparatus.
4. Main Drum Stripping Apparatus.
5. System of feeding Carding Engines with narrow Laps.
6. Lapping Machine for winding one or more Bands or Rovings on a Lap, with use of Doffing Knife.
7. Coil Frame, with Twisting Apparatus.
8. Double Coil Frame.
9. Improvements in Apparatus for forming the Cops in 'Throstle,' patented in 1837.—Also improved Flyer and Container.

No. 9,547, of 1842.

1. Construction of Tire Rolling Mill.
2. Squeezing Rollers for Puddling Furnaces.
3. Modified form of Tire Rolling Mill, with two Working Rollers.
4. Rolling Mill for producing Tires from Bars, not having originally the shape of Tires, or even from flat bars.—Internal Rollers governed by right and left-hand screw and weight, for keeping the Tyre steady under operation.—Supporting Rollers, to diminish friction and preserve the Table from wear and tear.
5. Machine for forcing Tires on Wheels.
6. Shearing Machine, adapted for preparing Plates to be subsequently rolled into Pulleys and other Hoops.
7. Tire-welding Machine.

No. 9,702, of 1843.

1. Improvements in Compensating or Double Piston Locomotive Steam Engines.—Expansion Gear, and mode of regulating the same.—Hand-Gear, Pistons, and Axle-boxes.
2. Tender.—Framing.—Break acting simultaneously upon the Rails and Wheels.
3. Tire Rolling Mill.—Gauging Apparatus to ascertain size of Wheel Tire.
4. Welding Furnace for Tires.
5. Peculiar construction of Compensating Crank.—Combination of Crank with Shaft, by means of Universal Joint and spherical Bearings.
6. Steam-engine Governor acting upon Expansion Valve.
7. Wheel with bent Spokes.

8. Mercurial Steam-regulating Gauge, to act in connection with the Safety Valve, and to let the surplus steam flow off to any place where it may be required, or to cause it to act against the Pistons of the Engine, so as to regulate its velocity more quickly.
9. Compound Compensating or Double Piston Steam Engine in connection with Paddle-wheel Propellers.
10. Wheel-break or Starting and Stopping Apparatus, as applied to Rolling Mills; and in combination with Paddle-wheel Propellers, to stop and start the latter instantaneously, though without any concussion and jerking, and without stopping the Engine.
11. Life-boat, with Fan-propeller fitted to it.—Various modes of jointing the Plates of Iron Vessels.
12. The Compensating or Double Piston principle applied to Pumping and Winding Engines.
13. Couplings of Pumprods and Shafts.
14. Modification of Starting and Stopping Apparatus, as applied to Winding Gear.

No. 9,899, of 1843.

1. Screw Fire-grate, with rocking motions of Bars.
2. Metallic Packing for Piston-rods, Pump-rods, and Cocks and Taps.
3. Lathe for cutting Pattern of 'drunken' Screw, to produce Rocking motion of Firebars.
4. Mode of applying Screw Fire-grate to Cementation Furnaces.—Mode of treating the Iron previously to packing it in the Boxes.
5. Continuous Cementation Furnace with spiral Flues.
6. Puddling Furnace, with Double Hearth: namely, an upper Hearth to smelt the Iron, and a lower one to form Balls.—Application of Screw Fire-grate to the same.
7. Smelting (Air) Furnace, in which the air is drawn down upon the hearth, from above, by means of a Fan.
8. Application of Screw Fire-grate to Air-heating Apparatus.
9. Band Saw, and mode of manufacturing the same.

No. 10,243, of 1844.

1. Outside Cylinder Compensating or Double Piston Tank Engine.—Brass Fire-box with Partitions.—Air-pump for forcing Atmospheric air into Boiler.—Fire-bars with rocking motion.—Brass Leading and Driving Wheels.—Elastic Connecting or Coupling Rods.—Expansion Apparatus.—Use of four Cylinders, of which the two internal ones are in connection with Crank-shaft, and the external ones in connection with Crank-pins.—Hollow Brass Piston-rod, in connection, or rather of one piece with the Slide-block and Pin.
2. Expansion Gear.
3. Mechanism for working Link-motion.
4. Tender.—Mounting Feed-pumps on Tender, and working the same from the running Wheels instead of fixing them to Engine as usual. —Improved Drag-links, with spherical or Ball-sockets, which are at the same time the tubes by which the water is conveyed from the Pumps to the Boiler.
5. Brass Crank-shaft, with eccentrics cast of one piece.
6. Four Modifications of Expansion Gear.
7. Valve for Atmospheric Railway.
8. Pair of 300 H.P. Horizontal Compensating or Double Piston Bevil-geared Screw Steam Engines.—Air-pump working at reduced speed. —Pipe, Cylinder-cover, and Cylinder Heating Apparatus.—Yielding Cylinder Top and Bottom, to prevent accidents through accu-

mulation of Water.—Application of Spherical Bearings to Screw-shaft.

9. Propeller Shaft Stuffing-box and Gearing.—Peculiar method of coupling and unshipping the Propeller-blades, which operations can be easily effected when under way.—Peculiar method of coupling the Propeller-shaft with the Engine.
10. 300 H.P. Stationary Inverted Cylinder Compensating or Double Piston Steam Engine, with external Crank.—Reduced speed Air-pump.
11. Modification of Variable Expansion Gear and Slide Valve.
12. High-pressure, Non-condensing Compensating or Double Piston Steam Engine, with Governor acting upon a Throttle Valve in the Exhaust Steam-pipe.
13. Expansion Valve Governor.
14. Steam Boiler with 'Bouloirs,' adapted for Screw Fire-grate.
15. Tubular Boiler.
16. 300 H.P. Horizontal, Compensating, or Double Piston Steam Engine, connected with a pair of Vertical Fan-propellers.—Peculiar construction of Propeller and Feed-box, and Regulating Apparatus.
17. Application of Friction Break or Starting Apparatus to Crank-shafts of Marine engines, for connecting or disengaging Paddle-wheel or Screw-propeller.
18. Application of Friction Break or Starting Apparatus to the end of a Shaft, for connecting the same with, or disengaging it from another Shaft, through the medium of a Universal Joint or Coupling.
19. Spherical Bearings, especially adapted for heavy Shafts, and where the Pedestals cannot be fixed to a solid foundation; as, for instance, for Shafts of Screw-propellers.
20. Application of Friction-break, or Starting Apparatus, to the Fly-wheel of a Rolling Mill, or other heavy machinery requiring to be suddenly started or stopped, and where the resistance to be overcome by the Motor is liable to be suddenly increased.—Also application of the same Apparatus for reversing the motion of the Rolls of a Rolling Mill.
21. Further modification of the construction of the Friction-break or Starting Apparatus.
22. High-pressure Tubular Marine Engine Boiler, fitted with Travelling Grate.—Inside Fire-box with corrugated Roof.—Water-bridge.—Fan blast with regulating Flues, for the purpose of giving any direction to the current of Air.
23. Balance-rudder, and mode of unshipping and replacing the same.—Metallic Tube to which the wings of the Rudder are attached.
24. Adaptation of the Compensating principle to Pendulum or Vibrating Steam Engines.
25. Inclined Cylinder Compensating Trunk Engine.—Air-pump for high velocities.

Mr. RHYS WILLIAM JONES, the eldest son of the late Mr. Rees Jones, of Penybaily House, Loughor, Glamorganshire, was born in Swansea in the year 1804. After receiving a liberal education, he became actively engaged under his father, who was a Mineral Engineer well known in South Wales, and likewise served a pupilage under the late Mr. Rennie. At an early period of his career he was employed under Mr. H. R. Palmer, then acting for Mr. Telford on the survey for the improvement of the turnpike

roads through Wales. Subsequently, when he had acquired a practical knowledge of the profession, he removed to London, and was occupied for some years, under the Messrs. Rennie, in connection with the Plymouth Breakwater, the New London Bridge, and other works then in progress. While the Sea Sluice and Embankment were in course of construction on the estates, near Lynn, in Norfolk, of the late Lord William Bentinck, he made the acquaintance of that nobleman, and was on the point of accompanying Lord William to India, where large engineering works were then projected, when the sudden illness of his father, Mr. Rees Jones, in 1830, who had been attacked with paralysis, and was unable to attend to active duties, recalled him to Wales.

When a railway between Liverpool and Manchester was first brought forward, he was engaged with Mr. Vignoles (V.P. Inst. C.E.) on the survey of the line projected by the Messrs. Rennie, and from that time railway communication occupied much of his attention. Shortly after Mr. Jones' return to South Wales, he constructed the harbour of Saundersfoot, in Carmarthen Bay, and acted as Mineral Engineer to the Pembrokeshire estates of the late Lord Milford. He was also engaged in the construction of the harbour of New Quay, in Cardigan Bay; but from the difficulty of raising the necessary funds the works were not completed at that time.

In 1846, when it was proposed to continue the Great Western system through South Wales to Milford, he took a great interest in the undertaking, and assisted the late Mr. I. K. Brunel in getting up the survey for part of the line through Glamorganshire and Carmarthenshire. The branch line to the town of Swansea was afterwards projected at his suggestion. The Vale of Neath railway was laid out by him, and was constructed under his direction, Mr. Brunel being the Engineer-in-chief. He was the Engineer to the Swansea Vale railway from its commencement, and also acted as Engineer to the Llanelly Harbour Commissioners, most of the improvements of that harbour having been carried out under him. He was also largely engaged in valuations of land for railways, and on arbitration cases, as well as on tithe commutation surveys in Wales.

Mr. R. W. Jones died on the 13th of April, 1864, at his residence, Pentwyn, Loughor, in his sixty-first year. His health had been failing for some time, but his death occurred rather suddenly, from an attack of paralysis. He was amiable and unassuming; was possessed of sound common sense, great integrity, and singleness of mind, and fulfilled the various duties of life in a manner to secure the esteem of all who knew him. He had been associated with The Institution of Civil Engineers for a long period, having

been elected a Member in 1835, and when in town frequently attended the meetings.

Mr. GEORGE RENNIE, the eldest son of the late Mr. John Rennie, F.R.S., &c.,—so well known by his numerous great engineering works in every part of the globe,—was born in the parish of Christchurch, Surrey, on the 3rd of December, 1791, and received the rudiments of his education at the establishment of the late Dr. Greenlaw, at Isleworth, whence he was sent to St. Paul's school, then under the management of the late well-known Dr. Roberts, where he remained about two or three years. From early life George Rennie was brought up under his father, with the intention of following the profession of a Civil Engineer, for which he exhibited considerable talent. In 1807 he accompanied his father in his annual professional tour through England, Ireland, and Scotland, visiting numerous engineering works. He was then placed at the University of Edinburgh, under the charge of the Rev. Dr. Robertson —a near relative of the distinguished historian—in whose house he boarded for about two years with Professor Dunbar and Dr. Henry, —subsequently the eminent chemist—of Manchester. At the end of this period he was received into the house of Professor John Playfair, by whose tuition he profited largely. During his stay in Edinburgh he studied mathematics, mechanics, natural philosophy, chemistry, and classics under Professors Leslie, Hope, Christison, Playfair, and Dunbar.

On his return from Edinburgh in the year 1811, he commenced the study of mechanical and civil engineering under his father, whose extensive engagements afforded him excellent opportunities for acquiring a thorough knowledge of the practical part of the profession. From this time he was in his father's office, who was then designing many great works, such as the Waterloo and Southwark bridges, the Lincolnshire drainage, the improvements of Plymouth, Portsmouth, and Chatham dockyards, and the Plymouth, Kingstown, and Holyhead breakwaters and harbours, &c.

In 1818, Mr. George Rennie was recommended, by Sir Joseph Banks and Mr. James Watt, as the successor of Mr. J. Lawson, for the situation of Inspector of Machinery and Clerk of the Irons (dies) at the Royal Mint, which post he held for nearly eight years. The duties of the department were laborious, requiring an intimate knowledge of machinery, as well as of the composition of iron and steel, and of the best mode of constructing dies for coining. Mr. Rennie was very successful, and his efforts gave great satisfaction. During the time he held the post he acquired that experience of the art of coining, which was afterwards turned to good account, when he was called upon to furnish (in

conjunction with Messrs. Boulton and Watt) the machinery for the Mints of Calcutta and Bombay, as well as for those of Lisbon, Mexico, and Peru.

On the death of Mr. Rennie, in 1821, Mr. George Rennie entered into partnership with his younger brother, the present Sir John Rennie, (Past-President Inst. C.E.,) and together they proceeded to complete the works of their father: among others, London Bridge, which was erected under the superintendence of Sir John Rennie, in consequence of the Government appointment then held by Mr. George Rennie. One of the most important works which they were called upon to complete was the dockyard at Sheerness, which was at that time regarded as the most systematic establishment of the kind in the kingdom. This was commenced after a plan made in 1813 by their father, and a more extended plan in 1821, the engineering works for the dockyard alone involving an outlay of about two and a half millions sterling. The cast-iron dock-gates which were then a novelty, have stood well to this day, the heelpost being accurately ground into the masonry to insure a tight joint. The success of these gates led many years later to the construction, under Messrs. Rennie's direction, of the ten pairs of large dock-gates at Sebastopol, which are described in a Paper read at the Institution of Civil Engineers.[1]

In 1826 he, with his brother Sir John, assisted by Mr. Vignoles (V. P., Inst. C.E.), laid out the present Liverpool and Manchester railway, and carried the Bill through Parliament. One of the most remarkable features of this line was the project for carrying the railway over the highest and widest part of Chat Moss, which was considered hazardous at the time, although it had been previously proposed by the late Mr. George Stephenson, by whom it was eventually executed, and it has turned out to be the cheapest part of the line. The estimate was £796,246, and the line was completed for £739,165. The gauge proposed by Messrs. Rennie was 5 feet 6 inches; but this, against their opinion, was afterwards changed to 4 feet 8½ inches, which probably caused all the subsequent confusion, and led to the celebrated 'battle of the gauges.'

About this time (1826) the late well-known architect, Mr. Harrison, made a design for a stone bridge of a single span of 200 feet to cross the Dee, at Chester. The boldness of the proposition induced considerable hesitation as to the undertaking, and the age and infirmities of Mr. Harrison precluding his executing the work, the Corporation of Chester consulted Mr. Rennie as to its practicability, which he confirmed, and he investigated the design thoroughly, equilibrated the arch in the most scientific manner,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vi., p. 47.

proposed to carry the foundations of the abutments down to the solid rock on both sides of the river, instead of—as had been originally intended—building one of the abutments upon piles, on the side where the rock was at a greater depth. The design, thus remodelled, was considered practicable; but nothing was done at the time for want of funds, the cost being estimated at £54.000. Eventually, the late Mr. Jesse Hartley, of Liverpool, was instructed to carry out the work, which he consented to do "on the condition that no alteration should be made from Mr. Harrison's external design, but that the interior and all practical points should be left entirely to him." He gladly availed himself of the scientific investigations of Mr. Rennie, and with the aid of the practical skill of the late Mr. Trubshaw, as the contractor, the present Grosvenor Bridge was built.

About the year 1836-37 Mr. Rennie, in conjunction with Messrs. Chapman and Jessop, laid out a line of railway between Birmingham and Liverpool, to cross the Mersey at Runcorn, with a magnificent viaduct. This was to have been connected with another direct line, by Sir John Rennie, between London and Birmingham, passing by the Valley of the Colne, Aylesbury, Bicester, Banbury, and Warwick, which was asserted by the promoters to be more level, easier of execution, and shorter than the present line. Mr. Rennie also laid out several other railways, including a line to connect the east and west parts of London, the Vale of Clwyd line, the Mons and Manège line, &c. In 1846 he was appointed Engineer-in-chief to the Namur and Liège railway, for which he designed three elegant stone bridges, the largest consisting of five arches of 80 feet span each, for crossing the Meuse, at Val St. Lambert.

During this period, and subsequently, at the mechanical engineering establishment of the Messrs. Rennie, in Holland Street, Blackfriars, important works were constructed, of a novel and difficult character, and at a time when the numerous appliances of tools and other arrangements for facilitating works in iron at present in use were comparatively unknown. In the construction of the two shields for the Thames Tunnel, one of the earliest, if not the first, machine on a large scale for planing iron was used, for the purpose of fitting together the different parts, and this machine is still to be seen in Messrs. Rennie's factory. Under the direction of Messrs. Rennie, the first machinery ever used for making biscuits was constructed for the Government establishments at Weevil, near Gosport. The idea of making biscuits by machinery is due to the late Sir Thomas Grant, and his views were carried into practical effect by Messrs. Rennie and their assistant, Mr. Gideon Scott. The corn and chocolate mills at the Deptford Royal Victualling Yard, as well as the more magnificent establishment called the

Royal William Victualling Yard, at Cremil Point, near Plymouth, were also due to the skill of the Messrs. Rennie; the latter being completed about the year 1835. Among other works may be enumerated the armoury at Constantinople, capable of making five hundred muskets a day for the Turkish Government; machinery for the arsenals of France, at Chatellerault, Toulon, and Rochefort; machinery for the Russian Government for producing biscuits and for making blocks at Nicolaieff and at Sebastopol, as also for coining at St. Petersburgh; besides engines for several large vessels of war propelled by the screw, including the 'Smalé' frigate, of 400 horse-power, the celebrated 'Wladimir,' of 400 horse-power, which was sunk at Sebastopol during the siege, the 'Peterhof' and the 'Alexandrina,' yachts of the late Emperor Nicholas, and other steamers on the Black and Caspian seas; likewise dredging-machines for Cronstadt, Odessa, and the Danube. Messrs. Rennie also designed the great steam factory at Cronstadt, and one, on a reduced scale, at Astrakhan. Messrs. Rennie constructed many marine engines for her Majesty's navy, such as the 'Samson,' 'Bulldog,' 'Vulcan,' 'Megæra,' 'Reynard,' 'Cruizer,' 'Oberon,' &c., and for her Majesty's yacht the 'Elfin.'

About the year 1836 Mr. Rennie took much interest in the propulsion of vessels by means of the screw. That propeller in various forms had been proposed and partially tried by Dugnet in 1727, Painton in 1768, Littleton in 1794, Shorter in 1802, and also by Napier, Tredgold, and Brown about 1825. In 1836 Mr. Francis Pettit Smith (Assoc. Inst. C.E.) fixed a screw propeller in the dead wood of the stern of a small open boat, and worked it by a high-pressure engine, making several successful trials with it on the Thames and to Ramsgate. Mr. Rennie and his brother, who saw it, were satisfied that it must eventually succeed on a large scale. A company was accordingly formed to carry it into effect. The 'Archimedes,' a wooden vessel of 232 tons, was built expressly for the purpose by Mr. Wimshurst; and Messrs. Rennie designed and constructed the engines, of 80 horse-power, with the machinery and the propeller. Notwithstanding the predictions of its failure by some of the best mechanical engineers of the day, who have since adopted it, the 'Archimedes' succeeded perfectly, and attained a speed of 9 miles an hour.[1] Messrs. Rennie subsequently, in 1840, constructed for the Admiralty an iron vessel, called the 'Dwarf,' of 210 tons, and fitted it with a pair of engines of 120 horse-power, with the requisite machinery and a screw propeller. This vessel, when completed and tried, attained a speed of $12\frac{1}{4}$ miles an hour, being 4 miles an hour in excess of the paddle steamers

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1839), p. 70.

then in use in H.M.'s navy. This was the first vessel propelled by a screw introduced into the British navy, and it produced a complete revolution in the military and commercial navies of the whole world. In 1852 Mr. Rennie also took up the subject of double or twin screw propellers, which had been previously proposed by Captain Carpenter,—a system now much in favour for light draft gunboats and for war purposes generally. Thus the first Mr. Rennie introduced the paddle steamboat into the navy in the year 1819, and his sons introduced the screw propeller into the navy in 1840, twenty-one years afterwards.

Having naturally a philosophical turn of mind, Mr. Rennie devoted his spare time to scientific pursuits, in making experiments and communicating the results to various scientific bodies. He was elected a Fellow of the Royal Society in 1822, was for several years one of the Vice-Presidents, and succeeded the late Sir John Lubbock as Treasurer, an office which he retained until the year 1850. In 1825 and 1826 he made a number of experiments on the friction of metals and other substances, the results of which were embodied in three Papers communicated to the Royal Society in 1828, and were published in the Philosophical Transactions.[1] These investigations still hold a place for accuracy and practical value, and at the time may be said to have been quite new, as they preceded by three years similar experiments made by General Morin, who, assisted by the French Government, pursued the subject further. Mr. Rennie was afterwards appointed one of the Royal Commissioners for investigating the strength of iron. In 1834 he wrote a valuable Paper for the British Association, "On the History, Principles, and Practice of Hydrostatics, Hydraulics, and Hydrodynamics," which, although now rather antiquated, is still considered a standard work. In 1840 he presented to The Institution of Civil Engineers an essay on "The Expansion of Arches,"[2] and in 1855 a "Description of the Bridge Aqueduct of Roque Favour, on the line of the Canal of Marseilles," as well as a "Description of the Pont du Gard."[3] In 1856 he communicated a Paper to the British Association, "On the Quantity of Heat developed by Water when rapidly agitated," also another "On the Resistances of Screw Propellers when revolving in Water at different Velocities." In the following year his Paper "On the Employment of Rubble Béton or Concrete in Works of Engineering and Architecture."[4] was read at the Institution, and was rewarded with a Telford Medal. He had previously written "On

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[1] *Vide* Phil. Trans. 1829. p. 143.
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1840), p. 4.
[3] *Ibid.*, vol. xiv., p. 190 and p. 236.
[4] *Ibid.*, vol. xvi., p. 80.

London, Metropolitan, and other Bridges," for Cooke's "London Bridges," and was the Author of several articles on dredging, mechanics, waterwheels, &c., in Weale's "Rudimentary Treatises," and in Weale's new edition of Tredgold. He also brought out a new edition in 1841, of "Buchanan's Millwork and Machinery," with all the latest improvements, to which an extensive supplement was added. He was likewise the Author of many miscellaneous Reports on Civil Engineering subjects.

In the year 1865, on his way home from the works in Holland Street, Mr. Rennie met with an accident from which he never recovered. He died on the 30th of March (Good Friday), 1866, in the seventy-fifth year of his age; and was buried, on the 5th of April, in the churchyard of the quiet country church of Holmwood Common, near Dorking, Surrey. He was married, in 1828, to Margaret Anne, daughter of the late Sir John Jackson, Bart., M.P., who survived him, and by whom he left issue two sons and one daughter.

Mr. Rennie was elected a Member of The Institution of Civil Engineers on the 4th of May, 1841, and served on the Council in the following year, and up to the period of his accident was a constant attendant at the meetings, taking part in the discussions and evincing great interest in the progress of the Society. He was also a Fellow of the Royal Irish Academy, as well as of the Academies of Turin and Rotterdam.

Essentially a man of science, both theoretical and practical, he would probably have attained the highest eminence had his attention been devoted exclusively to purely scientific pursuits. Combining great personal worth, simplicity of manner, and scientific attainments, it was no wonder that he possessed the regard and the esteem of all who knew him, and that, while professional intercourse alone was certain to produce lasting friendships, the advantage of a closer intimacy invariably secured unfeigned pleasure.

Mr. THOMAS RHODES, H. Mem. R. I. A., was born on the 7th March, 1789, at Apperley Bridge, near Bradford, Yorkshire, and received his education at Calverley school. His father, Mr. James Rhodes, was engaged in superintending the construction of the locks, gates, bridges, and other works on the Leeds and Liverpool Canal, when he met with a serious accident which disabled him for life. The eldest son William, was brought up to his father's business, that of a millwright and carpenter, when employed on the works of the Rochdale Canal. Mr. Thomas Rhodes, the subject of this notice, was apprenticed to his brother William, when under 14 years of age. He had thus an

opportunity of acquiring a practical knowledge of, and of taking an active part in, the construction of a variety of works, when the division of labour was not carried to so great an extent as at present. Having naturally a taste for mechanical drawing, he devoted himself in his leisure hours to making and copying drawings, which materially aided him in after-life. He remained with his broher for about eight years, and in 1810 was engaged for a short period on the Glasgow and Paisley Canal. In September, 1811, he proceeded to Corpach, at the western extremity of the Caledonian Canal, to take charge of and superintend the erection of the sea lock-gates, bridges, and machinery, the timber and ironwork of which had just arrived from England; and in the course of the following year the gates were hung in their places, to the satisfaction of Messrs. Jessop and Telford, the chief Engineers. As the timber for the other gates had not arrived, Mr. Rhodes was instructed to proceed to the eastern end of the canal, near Inverness, to erect the gates for the sea lock and the second lock. There being a difficulty in procuring timber suitable for any more wooden gates, plans were made for the use of cast iron; and after various experiments by Mr. Rhodes, the other gates throughout the canal were, with the full approval of Mr. Telford, constructed after the same pattern. The swivel bridges, dredging-vessels, hopper and other barges, were built agreeably to the plans prepared by Mr. Rhodes. During an interval of eight months, by order of Mr. Telford, he went to the Bonar bridge, then in course of erection over the Dornach Frith, and superintended the putting in of the coffer-dams, or caissons, and the erection of the scaffolding and centering for the stone arches and the cast-iron arch of 150 feet span. Having completed these works to the satisfaction of Mr. Telford, Mr. Rhodes left the Highlands and the Caledonian Canal in December, 1822. In the following year he was sent by Mr. Telford to take charge of the erection of the iron and woodwork of the Menai and Conway Suspension Bridges in Wales. In 1826, these bridges being finished, Mr. Rhodes was appointed by Mr. Telford Resident Engineer of the St. Katharine's Docks, London. During the execution of these works, Mr. Rhodes was engaged on the works of the Herne Bay Pier, reported on the Graving Dock near the Commercial Dock, London, made plans, specifications, and estimates for Belfast Harbour, a suspension bridge at Clifton, the Llanelly Railway and Docks, the London and Dover Road, and a new bridge across the Lagan at Belfast.

In 1831 he surveyed the River Shannon and its tributaries, for the Commissioners of Public Works, Ireland. In 1833, he made plans, specifications, and estimates for the improvement of the River Ouze, which comprised locks at Naburn and Linton, self-acting

wasteboard, jetties, slips for repairing vessels, and dredging vessels for deepening the channel of the river, and was likewise Engineer for the York Waterworks. The designs and estimates for the ship canal and floating dock, the New Bridge and waterworks at Belfast were also made at this time.

In 1834 he was engaged by the Exchequer Loan Commissioners to report on the Hartlepool Dock and Railway. He prepared a report and estimate for the completion of the Clarence Railway, of which he was afterwards the Resident Engineer, and he reported on the Ulster Canal. In 1835 he was appointed Commissioner for the improvement of the River Shannon; was engaged upon the harbour of Berwick-upon-Tweed; surveyed the River Derwent, and also a branch canal from the Staffordshire and Worcestershire Canal; he was Engineer for the Commissioners for the Limerick bridge and docks; prepared plans, specifications, and estimates for the Byer's Green Branch Railway, in Durham, and for the Stockton and Hartlepool Union Railway and Docks; and surveyed the River Severn, from Stourport to Gloucester, and made plans, specifications, and estimates for its improvement.

In 1839 Mr. Rhodes was engaged as principal Engineer to the Shannon Commissioners, to carry out the improvement of that navigation, involving works of considerable magnitude, comprising the large weir, &c., at Killaloe, Portumna Bridge,[1] the weir, lock, and gates at Mellick, Banagher Bridge, the Canal, Shannon Bridge, dredging and deepening the shallows, lock and weir at Roosky, Athlone, Lanesborough and Jamestown Bridges, with many other works of importance. At this period surveys were made of Loughs Neagh, Erne, and Corrib, also of the rivers Upper and Lower Bann, the Blackwater and Barrow, the coast of Kerry, for sites for piers and harbours, and various other works for the Commissioners of Public Works, Ireland.

In 1849 Mr. Rhodes was offered, by Messrs. Walker and Burges, the appointment of Resident Engineer of the St. Catherine Harbour Works, Jersey, and of the Harbour of Refuge, Alderney; and thinking that change of air would benefit his health, he accepted the appointment, and was stationed in Alderney, where he remained until 1860, when he finally retired from active life.

Mr. Rhodes was a very old member of The Institution of Civil Engineers, having been elected an Associate on the 27th of February, 1817, and he was transferred to the class of Members in the following year. His provincial engagements prevented his taking a very active personal interest in the Society, but whenever he was in London he always attended the meetings. It has been said by some of his contemporaries, that had it not been for his

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 99.

unobtrusive and retiring disposition, he might have taken a more prominent position in the profession, for which he possessed the highest qualifications.

Mr. Rhodes had been ailing for some months, when he suddenly expired on the 6th of June, 1868, in his eightieth year, at Paington, South Devon, deeply regretted by a large circle of relatives and friends, by whom he was deservedly beloved, for his urbanity of manner and kindness of heart, which had endeared him to every one with whom he was associated.

Mr. HERBERT GOULBURN ANDERSON, the youngest son of the late Rev. Robert Anderson, of Brighton, was educated at the Charter House, and began his professional career, in 1861, as a pupil of Sir Daniel Gooch, Bart., M.P., at the Locomotive Engine Works of the Great Western railway company at Swindon, where he underwent a practical training for two years, and where his proficiency gained the highest testimonials from those under whose instruction he was placed. He then went to Mr. Joseph Mitchell (M. Inst. C.E.), by whom he was sent on the Highland railway, and he assisted in the construction of most of the principal works upon the Ross-shire Extension of that line, and upon the Aberfeldy Branch, where he was engaged for two years, from 1863 to 1865. He was afterwards employed as an assistant engineer in the office of Mr. Fowler (Past-President Inst. C.E.); and then on surveys in Moldavia, and in Cumberland, for Mr. J. R. M'Clean, M.P. (Past-President Inst. C.E.). In the autumn of 1867, he was appointed one of the Inspecting Engineers on the "Railways (Ireland) Commission," in charge of the North East District, where he was occupied until January, 1868, and where he won the esteem of all with whom he came in contact.

He was elected an Associate of The Institution of Civil Engineers early in the year 1868, and frequently attended the Meetings. His cheerful submission to his leaders, his unselfish good fellowship with his companions, and his genial manner to all, rendered him a universal favourite; and no doubt his ultimate career would have been as prosperous and useful as the commencement was promising; but he died at the early age of twenty-six years, after a very short illness, in June, 1868. Few have lived more beloved,—none have died more regretted.

Mr. WILLIAM ROBSON COULTHARD commenced his professional career in the establishment of Messrs. Musgrave and Sons, Engineers, of Bolton, Lancashire, to which firm he was apprenticed. After the expiration of his articles he was engaged on various public works in England for about two years. He then

received an appointment under Mr. Vignoles (V.P. Inst. C.E.), as one of the assistant engineers engaged in the erection of the suspension bridge for the Russian Government over the Dnieper, at Kieff, in Southern Russia, where he remained for three years.

In 1852 he emigrated to South Australia, and entered into business as an engineer and contractor in conjunction with Mr. J. England (M. Inst. C.E.). Amongst other works which they were engaged in may be mentioned the bridge over the Torrens, near the Company's Mill, the bridge over the Wakefield at Auburn, and the erection of the jetty at Glenelg. In August, 1860, Mr. Coulthard was appointed Resident Assistant Colonial Engineer in the South-Eastern District, after which time he resided at Mount Gambier, and had charge of all the works in that extensive district, including public buildings, roads, bridges, jetties, and drainage. He built jetties at Port MacDonnell and Port Caroline, enabling both to become ports of shipment, and made good road-approaches to them and to Port Robe. While improving to a great extent the roads in the district, Mr. Coulthard also commenced an important system of drainage, by which many thousands of acres of agricultural land will, it is believed, be eventually reclaimed, and be brought into the market.

Mr. Coulthard was elected an Associate of the Institution on the 3rd of February, 1857. His death took place at Adelaide, South Australia, whence he had gone for the benefit of his health, on the 3rd of January, 1866.

It was a matter of regret that so active and zealous an officer, who had accomplished so much at so small an outlay, should be removed at a time when his knowledge of the district, combined with the improved resources of the colony, would have enabled him to take a part in the advancement of the material resources of the country which was placed under his superintendence.

Lieutenant ISAAC CURRAN, son of Private John Curran, of H.M. 69th Regiment of Foot, was born at Bangalore, in India, on the 5th of April, 1818. After receiving an education in the Military Male Orphan Asylum in Madras, he was drafted into the Gun Carriage Manufactory in 1835, where he soon attained such proficiency, that in November 1842 he was raised to the rank of Sergeant Instructor of a school established for the education of the artificers. In this school he is said "to have proved himself a useful auxiliary, encouraging all the artificers and pupils to read and improve their minds, and inducing men, who for years had never opened a book, to yield attention to their studies." He was promoted to the rank of Conductor in April 1847, being recommended "as a superior man in every respect: a scholar in mathematics, with a knowledge of the principles of construction of ordnance and labo-

ratory work; a plan draftsman equal to any officer or private in the Madras army," and "fully qualified as an instructor." In a letter, dated 13th September, 1849, to the superintendent of the Gun Carriage Manufactory from the Secretary of the Council of Education, Calcutta, it is stated that "Mr. Curran is a self-taught scholar, and a persevering, most intelligent practical officer, who has been mainly instrumental in bringing on the Institution;" and that it was at his recommendation Mr. Curran was made a warrant-officer. At an examination of the school in March 1849, at which Sir Henry Pottinger, Bart., the Governor, presided, his Excellency expressed his "high gratification with everything he had seen and heard of the progress the artificers and pupils had made in their several studies," adding, "It is very creditable to them, and particularly so to you, Mr. Curran." He was made a permanent Conductor in July 1854. It may not be irrelevant to refer to the testimony of the Honourable D. Elliot, a Member of the Madras Council, who, in his report of the Public Works Commission in 1854, remarking on the high character of many of the East Indians in the service, spoke of the principal subordinate officer, with the rank of Conductor, in the Gun Carriage Manufactory, as a most able man. For his "meritorious services, and especially for the valuable assistance rendered by him as a voluntary teacher for many years in the school of the Gun Carriage Manufactory, and desiring to mark their approbation of the zeal and energy which have characterized Mr. Curran's whole course, the Government were pleased, with the sanction of the Government of India, to confer on him the rank of Deputy Assistant Commissary on the 1st September, 1855."

Mr. Curran was sent to England in the year 1856, to select the steam machinery required for the Gun Carriage Manufactory, and while in this country, was elected on the 1st of December, 1856, an Associate of the Institution. The Governor in Council expressed his approbation at the satisfactory manner in which this duty was fulfilled, and Mr. Curran was raised to the rank of Lieutenant, in the year 1858, upon the warm recommendation of his superior officer, strongly supported by the Inspector General of Ordnance. The setting up of this machinery, including the shafting, pulleys, &c., for working it, besides an out-turn of ordnance work equal to two hundred sets of light field-carriages, occupied till October 1859. The manufacture of endless saws at a cost of annas 15-1, and a new mode of preparing rulers at a reduced cost, were originated by Lieutenant Curran at this time, and were fully recognized by his superiors. He continued to give valuable and efficient aid in conducting the duties of the manufactory down to the period of his decease, which occurred on the 4th of June, 1867, from softening of the brain, accelerated, it was believed, by the extreme anxiety and solicitude he felt about his work.

From the above sketch, it will be obvious that Lieutenant Curran was no ordinary servant. Within eight years of his admission, by a diligent cultivation of his talents, he was found not only to have acquired a theoretical and practical knowledge of his work, but also to possess an amount of information on other subjects, sufficient, in the estimation of his superiors, to qualify him for the post of instructor to the school, to which he was accordingly appointed; and by his unwearied devotion he succeeded in raising it to a position of respectability, which commanded the attention and support of the Government authorities, and brought himself into prominent notice. Eulogized both by the authorities and by his immediate superiors for his indefatigable zeal, energy, and special services, he was honoured with the unlimited confidence of the latter for his exemplary character, inflexible integrity, competent knowledge, and practical skill and tact; and for his untiring devotion to the interests of Government, not only in watching over and correctly accounting for the stores, but also in economizing the expense and working up to the greatest advantage the costly materials intrusted to his care. He passed through every grade in the department with credit, and deservedly won his promotion to a lieutenancy, within twenty-three years of his admission, for meritorious services rendered to the Government during his entire career.

Mr. CHARLES FREDERIC STUART SMITH was the only son of George Warwick and Maria Albinia Smith, of Derby, and the grandson of John ("Warwick") Smith, the eminent landscape painter, being also descended, on his mother's side, from Paul Sandby, R.A., the founder of the English school of water-colour painting, and from Thomas Sandby, R.A., the first professor of architecture at the Royal Academy, and Deputy Ranger of Windsor Great Park.

He was born at Shenstone, in Staffordshire, on the 21st of December, 1828, and commenced his education under the tuition of the Rev. J. Wakefield, of Derby, as a private pupil. Subsequently, from 1840 to 1846, he was a pupil of the Rev. Dr. Fletcher, Head Master of the Collegiate Grammar School, at Southwell, Nottinghamshire. With the view of taking orders in the church, he afterwards proceeded to Pembroke College, Oxford, where he completed his education; but as he felt a decided preference for an active professional life, and evinced a considerable talent for engineering, and a taste for scientific pursuits, his parents' idea of his becoming a clergyman was abandoned, and in July, 1850, he was articled as a Civil and Mining Engineer to Mr. John Woodhouse (M. Inst. C.E.). On the completion of his professional course of instruction, he became, in 1854, one of Mr. Woodhouse's assistants, and continued in that capacity until

December, 1858, when he received the appointment of Resident Engineer and Viewer to the extensive collieries, near Nottingham, belonging to Mr. Thomas North. Under the direction of the viewer, Mr. Smith succeeded in lighting the underground roads in the pits with gas; this being the first introduction of gas into mines in the Midland Counties. During this period he displayed considerable practical scientific knowledge of the ventilation of mines, and the precautions to be adopted for guarding against accidents by fire and after-damp, and also in the sinking and tubbing of deep shafts through heavily-watered and difficult strata, in the winning and sinking of mines generally, in the construction of branch lines of railway, the erection of buildings, bridges, &c.

In the year 1861, he commenced to practice the profession of a Civil and Mining Engineer on his own account in Derby, and received the appointment of Viewer to several important collieries in Derbyshire and Nottinghamshire, the duties of which office he zealously performed to the entire satisfaction of the proprietors.

The career of active usefulness and ultimate success, of which these various labours gave indication, was unhappily suddenly brought to an end. An attack of erysipelas in the head, induced by exposure to severe cold, after making an inspection of one of the mines in Derbyshire, terminated fatally, in the brief space of three days, taking him away in the flower of his youth, and at a time when, undoubtedly, a bright prospect lay before him. Mr. Smith expired at his residence, Wellington House, Derby, on Monday, the 8th of February, 1864, being little more than thirty-five years of age.

He was elected an Associate of The Institution of Civil Engineers on the 4th of February, 1862; he was also a Member of the Institution of Mechanical Engineers; and a Member of the North of England Institute of Mining Engineers. At the meeting of this Institution, held at Birmingham in July, 1861, Mr. Smith read a Paper, illustrated by maps, "On the Winning and Working of Cinderhill Colliery, near Nottingham."[1]

By urbanity of manner, assiduity in the performance of his duties, and kindness towards all with whom he was associated, Mr. Smith rendered himself deservedly popular; and deep was the sorrow of his wife, parents, relatives, and friends, at the loss of one who was so much beloved by all who enjoyed his intimate acquaintance.

Mr. JOHN VAUGHAN[2] was born of Welsh parents, at Worcester, on St. Thomas' Day, 1799. His father was an ironworker,

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[1] *Vide* "North of England Institute of Mining Engineers," Transactions, 8vo. vol. x., p. 149.

[2] Compiled from the local newspapers.

and was employed at Sir John Guest's works, Dowlais. At an early age young Vaughan was set to work in a scrap mill, and after a few years had elapsed, he became a puddler and then a mill furnaceman. Being a shrewd, practical man, clever and thoroughly acquainted with the whole of the processes involved in the manufacture of iron, he was speedily appointed foreman. Leaving Dowlais, he wrought for some time in large works in Staffordshire, after which he went to Carlisle, where he undertook the management of a small factory. He was now married and had one child—his son Thomas. Meeting with a better appointment, however, he left Carlisle, and was intrusted with the entire control of the extensive works of Messrs. Losh, Wilson, and Bell, at Walker, near Newcastle-upon-Tyne. In the course of business transactions on Newcastle Quay, he became acquainted with Mr. Bolckow, M.P., (Assoc. Inst. C.E.) at that time a partner with Mr. Allhusen, as a corn-merchant. Mr. Bolckow had accumulated some capital, which he wished to embark in the iron trade. Mr. Vaughan and he had frequent conversations on the subject, and ultimately it was arranged that they should enter into partnership, and begin operations at Stockton, a place where, it was thought, they would be likely to obtain land cheaper than on the banks of the Tyne, coupled with good shipping facilities. Mr. Bolckow went to Stockton in the latter part of 1839, but after making diligent inquiry, he failed to procure a suitable site for the new undertaking. The Stockton and Darlington railway had nine years previously, viz., in 1830, been extended to Middlesborough, 3 miles further down the river, where previous to the latter date there was but a solitary farm-house. The village was at this time simply a shipping place, doing a large coasting and continental trade in the coal and coke brought down from the pits in the Auckland district. Here Mr. Bolckow, disappointed at Stockton, chose a piece of land near the staithes, the greater portion of which was covered at high tide, and here Messrs. Bolckow and Vaughan erected their mills and puddling furnaces in 1840. For a few years their operations were restricted to the manufacture of finished iron. At that period the supply of ironstone was obtained from the nodules of iron existing in the coal measures, and a small quantity of hematite, which was imported; and Messrs. Bolckow and Vaughan, seeing the advantages which would accrue from having blast furnaces of their own, resolved to become pig-iron makers. Just about the time when their Middlesborough works were begun, the Stockton and Darlington railway was being extended through the Shildon Tunnel past Bishop Auckland and Witton Park to Crook and Stanhope; and during the next few years the Messrs. Pease were busily engaged in opening out new collieries at Roddymoor, Grahamsley, and the whole of the Crook

Valley. Messrs. Bolckow and Vaughan, therefore, were, on the face of things, quite safe in fixing on the south bank of the Wear, close to the Witton Park Viaduct, a spot where the coke of Crook and the limestone of Stanhope converged, for the erection of blast furnaces which were completed in 1846, and both there and at Middlesborough business was carried on with characteristic spirit. The iron ore was naturally expected from the coal measures, but unfortunately it did not turn out in quantities sufficient, and for four years the carrying on of the furnaces proved a serious difficulty to the partners, which was not lessened by the commercial panic of 1847, that swept over Middlesborough in common with the rest of the mercantile world.

It was this difficulty, however, which, by compelling Messrs. Bolckow and Vaughan to cast about for a remedy, was the direct cause of the success they ultimately achieved. Mr. Vaughan, who all this time had taken a practical part in the operations of the firm, mixing on the most familiar terms with the workmen, yet respected by all, knew of the existence of iron ore in Cleveland, and set himself to test its real value, and the result of his researches was the identification of his name with the actual rise of the Cleveland iron trade. Ages ago the upper seams in the dales were worked by the monks, if not by still more remote predecessors, as is proved by the heaps of scoriæ which are occasionally met with ; but up to the early part of the present century, nobody seemed to have dreamt of Cleveland competing with more favoured Staffordshire. In 1811, Mr. William Ward Jackson, of Normanby Hall, sent a couple of wagon loads of ironstone, obtained from his estate, to be tested at Lemington, and had the mortification to be told that it was good for nothing. In the same year, Mr. Jackson, of Lackenby, sent ironstone from the banks of Lackenby, now part of the Eston Ironstone Mines, but it appears to have led to little, if any result. Fifteen years later (1828) the coast from the Tees to Flamborough was examined, at the instance of the Birtley Iron Company, who were surprised at the slight traffic in iron ore carried on with the Tyne, by means of fishing cobles and small coasters. In the same year, Mr. Bewicke, of Sunderland, discovered the main seam ; a circumstance which Professor Phillips acknowledged in the following year. In this year (1829) also, Mr. Charles Attwood, of Towlaw Ironworks, met with good specimens of ore in the Hambleton Hills, and predicted that "Cleveland would become a great iron district when the railway system came be developed." In 1832, Mr. W. A. Brooks, (M. Inst. C.E.,) and Mr. T. Y. Hall, of Newcastle, testified that the adjacent rocks of Redcar contained large quantities of iron. In 1833, the Whitby and Pickering railway being in operation, ironstone was again sought for, and 55 tons were sent from Grosmont to the Birtley

Company's Works, where Cleveland ironstone was first used. The next year (1834) Lord Ward's agent, from Dudley, examined the Rosedale ore, and pronounced it to be limestone, not ironstone. In 1837, some more stone was sent to the Tyne Iron Company, who refused it, saying, "they were ashamed to see it lying on their quay." However, in 1839, the Birtley Company again tried the ore, reported favourably of it, and entered into a contract with the Whitby Ironstone Company for as much as 30,000 tons of one lot, at 10*s.* per ton of 22½ cwt., and a second lot at 9*s.*, which was delivered at the Pelaw staithes. After this time various firms appear to have used Cleveland iron, but its reputation made little way, and the trade was quite divided as to its merits.

All this was, however, but preparatory, and it was not until Mr. Vaughan, impelled by the necessities of the four furnaces at Witton Park, began his researches, that the real capabilities of the Cleveland iron deposits were even dreamt of. The circumstances of the actual discovery have been thus related by Mr. Holyoake in his sketches of Middlesborough:—"In June, 1850, Mr. Vaughan, taking with him Mr. Marley (M. Inst. C.E.), a man possessing great powers of discovery himself, they ascended the hill in Mr. Dryden's grounds, and they picked up pieces of ironstone, which led them to continue their ascent until they came to a quarry-hole, whence this ironstone had been taken for roads; and on entering Sir J. H. Lowther's grounds on the west, a solid rock of ironstone was lying bare, 16 feet thick. In twelve weeks after this discovery, Messrs. Bolckow and Vaughan had completed arrangements for working the mine, and had delivered 7 tons at their Witton Park Iron Works, and before six months were over 4,000 tons were sent out by them." After this the works of Messrs. Bolckow and Vaughan rapidly extended. Mines were taken at Eston, the furnaces at Middlesborough were increased, and the Witton Park branch was enlarged. The Cleveland iron was now loudly praised throughout the kingdom, and was soon universally appreciated.

The trade once fairly set on a firm footing by this fortunate discovery, for such it practically was, the indefatigable energy and remarkable skill of Mr. Vaughan were thenceforth devoted to its development. He suggested the increased height of furnaces, the marked success of which change has gradually led to the structures now seen. The manufacture of plates from Cleveland iron was another subject in which Mr. Vaughan took deep interest. It may be mentioned also, that for a number of years the firm did all its engineering under his superintendence. Into every department of the works he threw the greatest possible energy; and there can be no doubt, that he paid the penalty, in a lingering sickness, for years of harassing over-work. Mr. Vaughan was ac-

customed to make a point of personally inspecting every part of the increasing, and latterly, enormous, works of the firm, every day, travelling backward and forward between Eston, Witton Park, and Middlesborough, and taking the most minute interest in all that was going on. There was indeed something remarkable in the thorough division of labour in the management of the affairs of the firm. While possessing the most unbounded confidence in each other, the two partners never interfered in the slightest degree with each other's work. Mr. Bolckow had the entire management of the financial department, while Mr. Vaughan as worthily controlled the practical work of the establishment. The constant and close intercourse which existed between Mr. Vaughan and his workmen, and the kindly yet firm bearing he always showed towards them, endeared him to them, and none more sincerely mourned his loss.

Under the management of Messrs. Bolckow and Vaughan, their works gradually assumed gigantic proportions. Besides the furnaces at Witton Park and Eston they erected two additional furnaces at Middlesborough, where their works, including blast furnaces, puddling furnaces, rolling mills, foundries, and wharves, occupied a space of twenty-one acres. Their mining operations at Eston extended so prodigiously, that before many years were over, they sent out in prosperous times 2,000 tons of ironstone daily (the quantity in 1868 being nearly 3,000 tons); and they added coal mining to their other ventures, taking in hand several collieries in the Auckland district. Some idea of the magnitude of the works will be formed, when it is stated, that at one time—when trade was good—about five thousand men were in the employ of Messrs. Bolckow and Vaughan. This amazing increase from the small beginnings of 1840 does not, however, represent the whole of the results of Messrs. Bolckow and Vaughan's enterprise. Their successful essay was the precursor of all the numerous works which have sprung up in the district at the bidding of other capitalists from all parts of the country, and which raised the annual production of pig iron from 100,000 tons in 1853 to 1,250,000 tons in 1868, and made Middlesborough a town of nearly forty thousand inhabitants, while Stockton and villages down the river and nearer the ironstone mines increased as if by magic. The operations at length became too huge for a private firm to cope with. The labours of years, while bringing its well-won successes, told at the same time on the partners, and they desired to retire from active business. The Limited Liability Act offered the most natural means of effecting this change, and, accordingly, in 1864, a Company was formed under the title of Messrs. Bolckow, Vaughan, and Co., Limited, with a capital of £2,500,000, to take over the whole of the works. After the change in the management, Mr. Vaughan

did not take a very active part in the concerns of the Company, and, indeed, for eighteen months previous to his decease, he was totally incapacitated by sickness.

Mr. Vaughan was a member of the Town Council from the first incorporation of Middlesborough in 1853, and was third Mayor in 1855, Mr. Bolckow and Mr. Isaac Wilson being his predecessors. He was not, however, prominent as a public man, being more of a worker than a speaker, though he accepted office as a Borough Magistrate and as a member of the Tees Conservancy Board. His first wife dying, Mr. Vaughan, before he removed to Middlesborough, married a daughter of Mrs. Poole, of Newcastle, and sister of Mr. Bolckow's first wife. Of a genial disposition, and ever ready to help the deserving and the needy, he was generally beloved and esteemed, and by none more than by those who had known him longest. Whenever any project affecting the welfare of the public was set on foot, he unhesitatingly lent his aid to the scheme.

For two years previous to his decease, Mr. Vaughan had been unable to take any part in public affairs, owing to rapidly declining health; and paralysis setting in, he expired, after a lingering illness, on the 16th of September, 1868, in the sixty-ninth year of his age.

Mr. John Vaughan joined The Institution of Civil Engineers as an Associate on the 2nd of March, 1854, and when his avocations brought him to London, was an occasional attendant at the Meetings.

Mr. CHARLES WYE WILLIAMS commenced life as a Barrister; but this career he speedily abandoned, for, although in many respects fitted for the legal profession, his tastes lay entirely in engineering and commercial pursuits.

In 1806-7 Mr. Williams erected a large linen mill in Ireland, introducing, for the first time in that country, a new process called 'beetling,' and the finishing of linens, and also iron spur gearing, cast by Edwards, of Belfast. About the year 1819, he—with the intention, originally, of assisting Mr. John Oldham, the Engineer of the Bank of Ireland, and subsequently of the Bank of England—turned his attention to steam navigation, chiefly with respect to the introduction of Mr. Oldham's patent feathering paddles, which, after numerous modifications, became known as 'Morgan's wheel.' Mr. Williams consulted with the late Mr. A. Manby (M. Inst. C. E.), at the Horseley Ironworks, and thence was produced a small steam engine with two oscillating cylinders, the first of its kind and the precursor of all those which have since been so extensively used, with a pair of Oldham's feathering paddles. These were adapted to a whale-boat at the King's-end Foundry, Dublin, by Mr. Charles

Manby (Hon. Sec. Inst. C. E.), and the success was so great that the future career of Mr. Williams may be said to have been thus decided. Oldham's paddles were immediately tried on board the 'Aaron Manby,' the first iron steam vessel that ever made a sea voyage, and the general results of their trials were such as to lead to the formation of a steam company for the conveyance of passengers and goods between Liverpool and Dublin. The Company was established pursuant to the provisions of an Irish Act of Parliament—the 21st and 22nd George III., with a capital of £50,000. The partnership deed was registered, in compliance with the Act, in the name of one shareholder, who was called the acting partner: he alone being subject to the bankrupt laws, all the rest being merely sleeping partners, whose liability was limited to the amount of their shares. The firm was called Charles Wye Williams and Co., and the Company built, in 1823, the steamers 'City of Dublin' and 'Town of Liverpool,' each of 300 tons burthen. Mr. Williams was denounced as a bold and rash man, to commence such a speculation with two ships. However, as it turned out, there was a call for more capital and ships, and four additional steamers were laid down,—viz., the 'Hibernia,' 'Britannia,' 'Manchester,' and 'Leeds.' This growth of steam property caused the firm of Williams and Co. to merge ito the firm of the "City of Dublin Steam Packet Company." In this enlarged concern Mr. Williams found his fitting place as Managing Director, intrusted with the entire executive, assisted by a board of seven directors, for the financial and other departments. The increase of traffic continuing, Mr. Williams applied, in 1828, for a special Act of Parliament, 9th of George IV., "For regulating and enabling the City of Dublin Steam Packet Company to sue and be sued, and thereby to encourage the use of vessels propelled by steam in Ireland." This Act was obtained to enable the Company to place steamers on the Shannon, which river, at that period, had been surveyed, and on which a small steamer had been placed by Mr. John Grantham (M. Inst. C. E.). With the object of accelerating the introduction of river and lake navigation, Mr. Williams wrote a pamphlet, in 1832, on inland navigation, pointing out the capability of establishing an intercourse along the Shannon, from Lough Allen, in the north, to 46 miles below Limerick seawards. Mr. Williams claimed as the result of that pamphlet the appointment of a Commission. The Commission reported so favourably, that an Act was passed under which half a million sterling was expended on the improvement of the navigation. Ireland, therefore, is largely indebted to the indefatigable labours of Mr. Williams, for the extension of her inland navigation, and the improvement of her chief water artery.

As Manager of the City of Dublin Steam Packet Company his

duties were not light, for he had to keep pace with the times; and as the necessity arose for extending the operations of the Company, new capital and fresh parliamentary powers had to be applied for. The Company was granted a fresh Act of Parliament—the 6th and 7th William IV.; and in 1860 the Company, in conjunction with the London and North Western Railway Company, obtained an Act to enable them to raise the capital for the construction of the four powerful steamers, the 'Leinster,' 'Munster,' 'Connaught,' and 'Ulster,' which now maintain the service between Holyhead and Kingstown. Mr. Williams, at the ripe age of eighty years, took a warm interest in the completion of these vessels, visiting London specially to witness the casting of the cylinders of the 'Leinster' at the works of Messrs. Ravenhill, Salkeld, and Co. The City of Dublin Steam Packet Company continued to add vessel after vessel, until they possessed a fleet of thirty steamers of large capacity and great power. Mr. Williams acted as Managing Director of the Company to within a few years of his death, when he retired, full of honours, to enjoy that rest and repose to which a life spent in earnest persevering work entitled him.

One of the branches of Irish trade which has benefited greatly by an uninterrupted steam communication with Liverpool has been the cattle traffic, and had Mr. Williams and his contemporaries achieved no greater results, by the establishment of the steam trade between Liverpool and Ireland, than facilitating the transit of cattle to the English markets, they would have accomplished a great and almost national work.

Having successfully inaugurated and developed this important trade, Mr. Williams directed his attention to the possibility of bridging the Atlantic by steam communication. Some scientific men declared against the project, on the ground that no vessel could carry a sufficient quantity of coal for the voyage, leaving the requisite space for goods and passengers to make the scheme commercially profitable. However, the City of Dublin Steam Packet Company, acting under the advice of Mr. Williams and his co-manager, Mr. Francis Carleton, in the spring of 1837, built the 'Royal William,' and subsequently purchased the 'Great Liverpool' from the late Sir John Tobin, both of which vessels made several voyages to New York, shortly after the first trips of the 'Sirius' and 'Great Western.' The experience gained in this enterprise was that no private association could undertake such a service with success, unless supported by a public subsidy. Not being favoured with Royal patronage, the Transatlantic Company was dissolved. But Messrs. Williams and Carleton, nothing cast down by this pecuniary loss, launched a new company, under the title of "The Peninsular and Oriental Steam Navigation Company."

The 'Great Liverpool' was transferred to this new project, and formed one of the fleet of steamers destined to open up the overland route to Egypt. Although the 'Great Liverpool' had a short career, her proprietors were not wrecked, for the Peninsular and Oriental Company has now the largest capital of any Steam Company, and owns the greatest amount of tonnage.

As possessing by-gone interest in steam matters, it may be noticed that Mr. Williams saw the difficulty of securing the engines to the ship's framing. Engineers and ship-builders could not be made to act together; so Mr. Williams had a template, or pattern, made of the bottom, or bedplate of the engines, and marked the position of the holding-down bolts by which the engines were secured to the framing. Observing that not one-half of these bolts would have gone through floor timbers, but had no other holding than the 4-inch outside planking of the vessel, he inserted additional floor timbers, held by four sister keelsons. There are now so many iron-built and iron-framed steam vessels, that this original difficulty of holding the engines seems incredible; but it was not until after the building of a few vessels that this weakness was discovered. Mr. Williams had in many cases to act as his own engineer and naval architect, and at a very early date he applied water-tight bulkheads, to divide a ship into separate compartments, which he suggested for the iron steamer the 'Aaron Manby;' and this great improvement formed the subject of a communication which he presented to the British Association in 1837.

In the course of an experience in the building and equipping of ships, perhaps extending over a longer period than that of any other Director of Steam Packet Companies in England, Mr. Williams had perceived that "notwithstanding the improved state to which the construction and appointments of the hull and general machinery of steam-vessels had arrived, great uncertainty and risk of failure still prevailed in the use of fuel and the generation of steam." The first edition of his essay on "The Combustion of Coal and the Prevention of Smoke, chemically and practically considered," is the result of his investigations; and the City of Dublin Steam Packet Company, by desire of the Directors, assumed the whole cost of the publication. The work was accompanied by large coloured diagrams, illustrating the atomic mixture and combustion of the gaseous and solid elements of fuel with oxygen. His views on combustion are generally acknowledged to be sound, while they are expressed in a popular manner which every one may understand. This treatise has gone through several editions, and has been translated into French, under the auspices of the Minister of Marine. Whether it has really led to the better combustion of coal in land furnaces has been doubted, but there are many cases where the subdivided air jets have been employed with

the best results. In locomotive engines it is only the application of the principle, so clearly urged by Mr. Williams, that of a regulated admission of air over the fire, that has enabled coal to be substituted for coke, burning the former with but little smoke—often with scarcely any whatever. In 1856, Mr. Williams received the Society of Arts' gold medal for his essay "On the Prevention of Smoke," from the hands of the late Prince Consort, at that time the President of the Society.

In his laboratory at "The Nook," near Liverpool, he had a model boiler and furnace, to exemplify the principles he had laid down, and for which he contended so pertinaciously. With this invention he became a competitor, in the exhibition of marine steam-boilers at Newcastle, for a prize of £500. The professional umpires on that occasion were Sir William Armstrong, Dr. Richardson, and Mr. Longridge, and they decided in favour of Mr. Williams's system, which they pronounced to be "applicable to all descriptions of marine boilers," while "its extreme simplicity is a great point in its favour." While retaining the enduring honour of this triumph, Mr. Williams presented the £500 to a popular institution, acting in that case, as throughout the whole history of his efforts for the perfection of steam-navigation and for the recognition of the simple laws regulating the combustion of coal and the prevention of smoke, with that indifference to personal gain which, throughout his eminently useful and active life, was one of his distinguishing characteristics.

Although during the greater portion of his long life Mr. Williams was essentially a man of business, he was also an ardent lover of science; and it is from his scientific writings, rather than from his practice, that his name has become so widely known. Besides the treatises already referred to, and Papers in the Proceedings and Transactions of various Societies, in 1860 appeared his last work, "On Heat, in its Relations to Water and Steam."

To plan and carry out all the ideas originated by Mr. Williams required a large share of tact, talent, and industry. He was fortunate in having the means at his command, and the opportunity to enforce his views, to prove that practicable which, to other minds, would appear to be mere shadowy theories. It is by the ingenuity and perseverance of such men as Mr. Williams that England owes her pre-eminence as a maritime nation. He cites, as his incentive to work, the words of Roger Bacon—"That among the grounds of human ignorance are the trusting to inadequate authority and the force of custom. As the slaves of habit, we are still found following the untaught crowd, and flinch from the wholesome phrase: 'We do not know,' the remedy for which is honest research, original and independent thought, with strict truth in the comparison of what is already known by others."

Mr. Williams was not wedded to the force of custom; hence he achieved great objects, and lived to point to changes carried out under his auspices, which at times had been stigmatised as empirical or presumptuous.

Mr. Williams was elected an Associate of The Institution of Civil Engineers on the 16th of June, 1835, was a frequent attendant at the meetings, and frequently took part in the proceedings. His death occurred on the 2nd of April, 1866, in the eighty-seventh year of his age. To rich and poor alike, Mr. Williams was the same quiet, unobtrusive, approachable Christian gentleman. By men of science he was universally esteemed and admired; by his private friends he was deeply loved, and by all who knew him he was honoured and respected.

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